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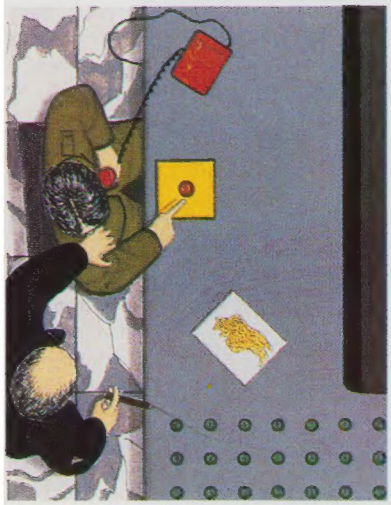

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Field Notes

Jonathan Weiner

Henri Rousseau, The Dream, *1910*

In Gaia's Garden

Seven years ago, a maverick chemist named James Lovelock published a queer little book, *Gaia: A New Look at Life on Earth,* in which he expounded a view of nature that seemed more in harmony with the intuitions of old-world farmers than of twentieth-century scientists. He argued that the planetary kingdoms of animals and plants and bacteria are working together to keep Earth livable. All that creep or crawl or grow, from Greenland to New Zealand, from Novaya Zemlya to Palau, from the tortoise to the termite to the trypanosome, play some part in the global cooperative. Life, said Lovelock, is more than a passenger on the planet. It is the creator of soil and air and it maintains the seas. Life shapes Earth to its own ends. Or, to put it another way, the whole planet—not just its flora and fauna but even its rock, water, and air—is alive. This blue Earth is a single cell (as the biologist Lewis Thomas described it); its inhabitants, together with its spheres of air, water, and rock, are the cell's working parts, its organelles.

Lovelock's book sounded to many readers like myth spinning. Indeed, its very title is mythological: Gaia was the Greeks' earth goddess, Mother Nature (her name was recommended to Lovelock by a neighbor, the novelist William Golding). Though the biologist René Dubos praised Lovelock's daring book in *Nature* and the physicist Philip Morrison touted it in *Scientific American,* and though Thomas had popularized its point of view in *The Lives of a Cell,* more common reactions from Lovelock's colleagues were silence or snorts of derision. I suspect that most readers today think Gaia is dead and buried.

But the little book continues to circulate, not only among Friends of the Earth but among those who matter if the Gaia hypothesis is to influence scientific thinking. Many geochemists, atmospheric chemists, and ecologists are still reading *Gaia,* or rereading it, usually in the small hours, after a hard day's work sampling trace metals in a coastal estuary or measuring ozone levels in the South Pacific or quantifying the relationship between the saguaro cactus and the kangaroo rat. The Gaia hypothesis may yet prove to be one of those provocative ideas that advance the understanding of nature, by encouraging supporters to view their local data in new (global) ways and by forcing opponents to sharpen their knives.

Recently, a climatologist, Stephen Schneider, of the National Center for Atmospheric Research, in Boulder, sent colleagues a letter proposing an international conference. The event will take place some time in 1987 (if it receives funding). Participants at the Gaia Conference, including Lovelock, will debate whether life on Earth is actively controlling and maintaining the planet's climate. Speakers from a broad range of earth sciences will wage battles for or against Gaia on land, in the air, and in the sea.

Lovelock himself, being an atmospheric chemist, sees his best evidence for Gaia in the air. As he noted in his book, the air we breathe is an unstable and improbable mix of gases: twenty-one percent oxygen, for instance, and only three-hundredths of a percent carbon dioxide. The concentrations of these gases (as of others in the atmosphere) are vital to life on Earth, but they are, from a chemist's point of view, almost unnatural; as Lovelock puts it, "they show a high degree of contrivance."

Before life began, there was virtually no oxygen in the atmosphere. When the distant ancestors of today's plants invented photosynthesis, some two billion years ago, they casually released oxygen as a by-product. The evolution of most plants and animals since that day has been fueled by the gas, and most species alive today could not do without it. But oxygen is highly reactive, volatile. It combines readily with other gases in the atmosphere, and minerals in Earth's crust and in the sea are continuously pulling it out of the air and burying it (the rusting of each iron fleck in a pebble takes a bit of oxygen out of circulation). If plants were to pump much less oxygen, or if the inanimate Earth were to retrieve much more of it, life would be starved of this chemical fuel on which cellular respiration depends. On the other hand, if plants were to pump much *more* oxygen, its concentration in the atmosphere would become dangerous, and vast stretches of forest might burst spontaneously into flames. Between oxygen depositors and oxygen withdrawers, the global balance must be very finely tuned.

At the same time, Earth's crust has exhaled carbon dioxide in great quantities from volcanoes and from vents in the sea floor. If all this carbon dioxide had been allowed to accumulate unchecked, it would long ago have become the dominant gas in the atmosphere. But carbon dioxide is removed from the air by plants and animals, which use carbon as the backbone of every organic molecule in their leaves, stems, bones, and bodies. Again, the balance of this gas depends on the actions of both the animate and the inanimate Earth, and, again, the balance is crucial to the survival of life. Carbon dioxide is a greenhouse gas; it keeps Earth's body heat from radiating rapidly into space. With less carbon dioxide, the planet might freeze; with much more of it, the seas would boil away. (On Venus, the atmosphere is almost pure carbon dioxide, and the seas appear to have evaporated long ago, leaving their basins as vacant as the staring sockets of a skull.)

Thus life gives Earth its peculiar atmosphere, which, in turn, keeps the climate comfortable and the seas safely in their beds. Our atmosphere, says Lovelock, "is not merely a biological product, but more probably a biological construction: not living, but like a cat's fur, a bird's feathers, or the paper of a wasp's nest, an extension of a living system designed to maintain a chosen environment."

To say that plants and animals shape climate is to turn the old view of life on its head. A more familiar perspective is the one Rachel Carson painted near the beginning of *Silent Spring:*

> The history of life on earth has been a history of interaction between living things and their surroundings. To a large extent, the physical form and the habits of the earth's vegetation and its animal life have been molded by the environment. Considering the whole span of earthly time, the opposite effect, in which life actually modifies its surroundings, has been relatively slight. Only within the moment of time represented by the present century has one species—man—acquired significant power to alter the nature of his world.

But this view, which once seemed self-evident and commonsensical, is no longer widely accepted among earth scientists and ecologists. It is inevitable that quintillions of cells living and dying on a small planet should change the place, and scientists are now sure that primordial life shaped the chemistry of the atmosphere; that the presence of life—the sum of all of Earth's biota—still affects it (adding and subtracting huge quantities of gases); and that life's contributions have powerful influences on the global climate.

Most scientists wouldn't go so far as Lovelock. They wouldn't say that life's influences are necessarily self-serving. Whereas some of life's exhalations may help keep the global climate in balance, others may unsettle it. There are winners and losers in any climatic shift, since some like it hot, and some do not. Still, life and climate did evolve together, and they continue to coevolve. That is the new scientific consensus, and if Lovelock had said no more than that in *Gaia*, he would not have shocked so many earth scientists (though he might have startled the rest of us, who are still trying to take in this new view, with its myriad interlocking parts).

Lovelock contends that life's influence is not just random pushes and shoves, some good and some bad, but that life itself keeps the global climate benevolent. Bacteria in the guts of termites, for instance, make methane; there are so many termites in the world (perhaps as many as half a ton's worth for every human being) that they are a major global source of this gas. When methane enters the atmosphere, the gas ends up doing at least two things: like carbon dioxide, it helps retain the planet's body heat; and like iron-bearing rocks in Earth's crust, it helps remove oxygen from the lower atmosphere and thus keeps our world from catching fire. Lovelock would say that bug gas is a part of Gaia's strategy: the world's termites are, in effect, working with the world's trees to keep the air just right for the maintenance of life.

Even some of Lovelock's most sympathetic readers—including Schneider, the organizer of the Gaia Conference—think that this is going too far. They accept that termites produce methane, but they can't believe there's a master plan. They just don't think life is that smart. It is much easier to assume that termites do one thing and trees another: sometimes it helps; sometimes it hurts; and the world limps along. As Schneider says, "I believe that life and the environment have coevolved, but I also believe that those interactions have not always been optimum to all forms of life, but simply interactions which lead to mutual change—some beneficial and some detrimental for some forms of life at some times."

This is the aspect of Lovelock's book that strikes so many readers as ludicrously unscientific—the idea that lichens, trees, termites, and apes are somehow planning together, working for the good of the group. Can the planet's hodgepodge of species really cooperate, like an ethnic bomber crew in an old MGM movie, to keep Earth on target? Can even one species steer its own fate?

The Canadian biochemist W. Ford Doolittle, of Dalhousie University, has raised these questions. Evolution, he has pointed out, proceeds without plan or foresight, by natural selection. In each generation, the individuals that are fittest to survive and reproduce tend to leave the most offspring. The offspring vary slightly from one to the next, the variations making some a bit more fit than others to survive and reproduce. Thus, over time, natural selection is powerful enough to determine all the intricate diversity of life.

Doolittle can't see how Gaia, which represents global cooperation among species, could evolve by natural selection, whose theme is incessant competition among individuals—Tennyson's "nature, red in tooth and claw." Lovelock's vision, says Doolittle, reminds him of the world of Doctor Dolittle:

> In Hugh Lofting's book *Doctor Dolittle in the Moon,* John Dolittle marvels at the absence of Darwinian competition among the lunar flora and fauna. This, it turns out, reflected the dominance of 'The Council,' which was 'made up of members from both the Animal and Vegetable Kingdoms. Its main purpose was to regulate life on the Moon in such a way that there should be no more warfare.' Dolittle remarks to his aide, 'our world that thinks itself so far advanced has not the wisdom, the foresight, Stubbins, which we have seen here. Fighting, fighting, fighting, always fighting! So it goes down there with us... The "survival of the fittest"!... It is this thing here, this Council of Life—of life adjustment—that could have saved the day and brought happiness to all.' Lovelock's Gaia is very much the terrestrial equivalent of Lofting's lunar Council. But the Council was created by Otho Bludge, the first moon man and a refugee from Earth. Who created Gaia?

That is, Doolittle believes that Gaia could be created only by conscious and careful design.

Lovelock and the Boston University microbiologist Lynn Margulis (his chief collaborator on this controversial hypoth-

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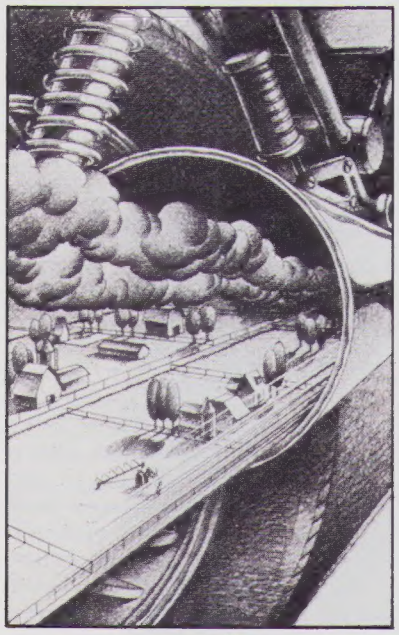

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esis) are convinced that natural selection *could* have created Gaia. Regrettably, their argument relies upon an esoteric field—cybernetics (the discipline that gave us the term *feedback*), which, as Lovelock defines it, is "concerned with self-regulating systems of communication and control in living organisms and machines." When Lovelock starts talking cybernetics, he loses most scientists. He says (a shade haughtily): "I suspect that most scientists still reason in the cause-and-effect manner set by Aristotle. The circular and recursive logic of whole systems is alien to them. This is especially true of geologists, geochemists, biochemists, and exobiologists who might otherwise have been interested in Gaia."

Not long ago, trying to fathom Gaia, I remembered a game my father played with my brother and me some twenty years ago. It sounds incredible, but we built a computer out of shirt cardboard and Dixie cups, and the contraption quickly got smart enough to outwit the three of us at a game of strategy. I still recall our delight as we sat at the kitchen table and watched the Dixie cup computer making better and better moves, until, by the end of the evening, it trounced us every time.

The computer had been invented by a mathematician at Cornell University, Henry David Block, who had been interested in "mechanical biology"—in designing simple gadgets that do things we had once thought only life could do. In the March 1965 issue of *American Scientist,* Block had shown how easy it is to build a computer that can learn.

Block called his computer G-1 (*G* for Golem, the robot slave of medieval Jewish legend, a lump of clay that a mystic brought to life by whispering to it the name of God). G-1 consists of a row of Dixie cups numbered 1 through 12, with three small cards (cut from shirt cardboard) numbered 1, 2, and 3 in each cup. It is entertaining to place the row of cups so you and Golem face each other across the table like two human adversaries.

The game that Golem plays is called Nim. Block experimented with some complicated variations, including the use of dice, but a simpler version begins with twelve checkers heaped in the middle of a table, like a pot in a poker game. When it is your turn, you have the choice of removing one, two, or three checkers from the heap. Then the computer has the same option. To learn the computer's move, you count the total number of checkers still in play. Then you go to the cup bearing that number and withdraw, at random, one of the cards. The number on the card is the computer's move. Human player and computer alternate, politely taking turns, and the last one to remove a checker, or checkers, loses.

It is Golem's move at the start of each game. You shake Dixie cup number 12 and, at random, remove a card. The card says 2. So the computer's move is to take away two checkers (true, you're doing Golem's legwork, but *it's* doing the brainwork). Then you move. And so on.

The secret of Golem's aptitude for Nim lies in what happens to its cards. After the computer plays a card, you place the card just outside the cup it came from and leave it there until the end of the game. Then, if the computer wins that game, you return all the cards it played to their respective cups. But if the computer loses, you throw the card bearing its last move (the move that just cost Golem the game) into a discard box and return the other cards to the cups they came from.

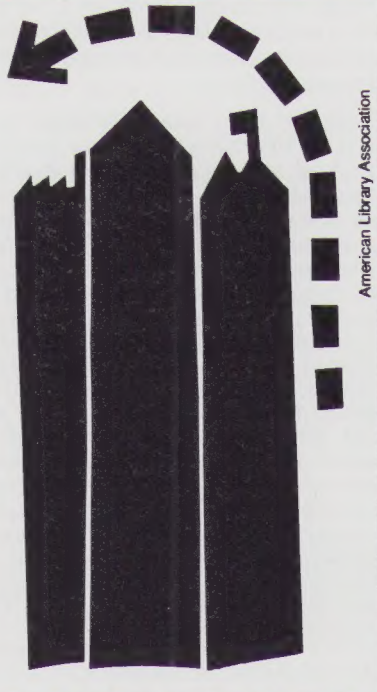
At first, since Golem plays 1, 2, or 3 at random, it loses more often than it wins. But each time Golem makes a losing move, that move is pitched into the discard box and is thus stricken forever from Golem's repertoire. By this process of natural selection, the computer makes fewer and fewer dumb moves, and more and more smart ones.

Some cups, of course, don't contain any winning moves. Cup 1, for instance, enters a game only when there is a single checker left. Golem may opt (blindly) to remove two or three checkers, but because there is only one checker in play, these moves are illegal, and Golem loses the game. Or Golem may choose to remove one checker, a legal move but just as fatal, since we're playing Last One Loses. After Golem has tried each of these moves once, cup 1 is empty forever.

It is fascinating to watch Golem learn to work around this trouble spot and win games. Say there are four checkers left on the table toward the end of a game. It is the computer's move, and since you've played only a few games with it so far, it is still stupid. Dixie cup 4 contains all three of its cards. Golem, let's say, chooses to remove one checker. Smirking, you remove two. Cup 1 is empty, so Golem forfeits the game, and you throw out card 1 from Dixie cup 4.

A little later in the evening, a few more games down the road, there are, once again, four checkers on the board, and it is Golem's move. This time, perhaps, it plays the card numbered 2. That leaves two checkers on the table, and it's your turn. You pick up one checker, with a snort, and Golem loses again. Card 2 is discarded.

A half-dozen games later, the same situation occurs, but now Golem knows exactly what to do, because it has only one move left in Dixie cup 4, the card marked 3. That move wins the game. So you return the card to its cup, and, from now on, faced with four checkers, Golem will win



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the game every time. It simply has forgotten how to lose. Moreover, it will now learn how to *set up* that winning situation, because moves that lead to losing situations will be removed, one by one, from its memory. That is the most ingenious feature of Block's invention: the way the twelve Dixie cups inexorably evolve a sort of strategy, or global game plan.

If you graph Golem's wins against its losses, you'll see that its success rate climbs slowly for dozens upon dozens of games, and then soars. After several hundred games, Golem plays Nim like a master. Nothing but cardboard, it gives every appearance of foresight and planning. A strong move by cup 10 sets up a fine move by cup 7, allowing cup 4 to win the game. As Block puts it, "In the performance of these machines it is interesting to observe how a simple *local* 'law of change' results in a *globally optimal policy.*" In short, Golem's cups work together with diabolical intelligence.

Lovelock's vision of Gaia, with life *wisely* influencing climate, seems much less incredible once you've built a golem and watched it in action. It is humbling to be beaten by a set of Dixie cups. If natural selection can do that much for cardboard, what can it do for species? We know that the harsh tests of time and climate cause countless species to go extinct—to fall into the deep, dark discard box of history. We know that the survivors are those with winning ways, those most able to cope with the local climate, and with each other, and to survive round after round, year after year. We know, too, that many of these species, by their living and dying, alter the sea around them and the air above them. In time, couldn't natural selection lead to "a globally optimal policy," with African gorillas and Antarctic lichens appearing to work together for the success of the living planet? Golem learns —why not Gaia?

I'm sure that an ecologist schooled in the circular and alien logic of cybernetics could extend this analogy more surefootedly than can I. But I picture each of the Dixie cups as a separate climatic zone, and the cards in each cup as an assortment of species adapted to life in that zone. In some of Gaia's cups, there are very few winning moves, and these cups are nearly empty. In others, there are many winning moves, and those cups are nearly full. Cup 3, for instance, is Antarctica, where just about the only species with winning ways are emperor penguins and lichens that shelter themselves inside rocks. Antarctica was once a balmy place, with a profusion of flora and fauna. But when it was plunged into cold, millions of years ago, by the drifting of continents and the shifting of ocean currents, most of its species fell into the discard box. Cup 12 is the Amazon rain forest, where the seasons are mild and muted and there are a half-million or more species with winning ways, from strangler figs to morpho butterflies to harpy eagles. The sum of all these climatic zones, and of all the species in them, is the biosphere, or Gaia, just as the sum of all the Dixie cups and their cards is Golem.

Each species, in small ways or large, influences global climate. So the species in cup 12 are helping determine the survival of those in cup 3, and vice versa, just as in the Dixie cup computer. If the Amazon rain forest ever stops putting out its rich home brew of gases, for instance, it might throw Gaia's whole atmospheric strategy off kilter. Countless species all down the line might drop into the discard box. This is one threat of the sweeping deforestation in Amazonia today.

Since each species must someday pass away (something like ninety-nine percent of all the species that have ever lived are now extinct), we're fortunate that Gaia's fate does not depend on any single animal or plant. Having millions of species, and God knows how many individuals, in the game at any one time gives Gaia stability and allows her to cope with the unexpected. This process, too, we can glimpse in the Dixie cup computer. Block experimented with different ways to help it learn. For a more interesting game, he suggested, don't discard a losing move but instead *add* copies of the winning move to the cup. That's precisely the mechanism by which Lovelock and Margulis believe that Gaia learns. While species with losing hands drop out of the game, species with winning hands multiply in the cup. Thus does Gaia fine-tune her game.

Block also toyed with variations on Nim in which the winning strategy was beyond the reach of all but a mathematical games expert. He discovered that the strategy's intricacy made no difference whatever to his Dixie cups; they learned winning ways just as quickly and surely as ever, by natural selection. Block realized that, in principle, with enough cups, cards, and patience, he could build a computer capable of winning tic-tac-toe, checkers, or even chess.

I can imagine Gaia as just such a myriad-cupped, million-carded gizmo. She is playing games too mysterious and complicated for us to understand. She has been tested, nonstop, for four billion years, and by the time you and I started watching, Gaia had grown, to all appearances, as wise as a goddess—or a golem. ●

JONATHAN WEINER is a contributing editor of THE SCIENCES. *His book,* PLANET EARTH, *the companion volume to the PBS television series, was recently published by Bantam Books.*

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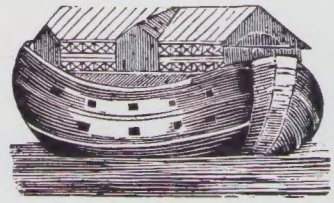

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Jim Dine, Child's Blue Wall, *1962*

Physics Finds a Childhood

Tradition has it that the door to Plato's Academy, in Athens, bore the forbidding inscription, "Let no one enter who is not a mathematician." Geometry, for Plato, was the supreme example of pure reasoning—abstract, immutable, detached from human affairs, as close to absolute truth as one can get. Thus, it provided the perfect intellectual training for philosophers. Accordingly, the academy's students—among them Aristotle, whose thinking was to dominate physics for almost two millennia—acquired a solid mathematical education.

But Plato wasn't the only teacher in Athens. Overshadowing his academy in prestige and popularity was the school of Isocrates, the orator. For more than fifty years, Isocrates taught the elite youth of Greece, and his influence on the great politicians, writers, and historians of the age was enormous. At the core of his philosophy stood *logos,* the word. Through language, he wrote, "we have come together and founded cities and made laws and invented arts." Language, in brief, is what made us human. Whereas Plato insisted on the study of mathematics, Isocrates emphasized rhetoric, literature, and history. Thus, even as science was beginning to stir in the womb of philosophy, it was faced with a choice of directions. Would it follow Plato along the path of mathematical idealism, or would it become part of Isocrates' literary and historical humanism?

At first, the odds seemed to favor Isocrates. Physics, for instance, was largely narrative in the beginning. The Roman poet Lucretius cast the atomic theory of the early Greek philosopher Epicurus in verse form, in his celebrated poem, *On the Nature of Things*. In more than seven thousand lines of heroic hexameter, Lucretius attempted to deduce all the rich complexity we observe in nature from a handful of fundamental axioms. Though the poem did not anticipate the modern conception of atomic structure, it served to keep alive the doctrine of atomic materialism—that everything in the universe is composed of bits of primal matter—that is the basis of today's physical world-picture. And even much later, in the seventeenth century, Galileo published his fundamental mechanical and astronomical discoveries in the form of dialogues written in the colloquial Italian of his fellow citizens.

But the end of the literary mode was in sight; by the second half of the seventeenth century, the age of Newton, equations had replaced words as the vocabulary of physics. From that time, until quite recently, physics concerned itself solely with quantifiable facts and the elucidation of their complex interrelationships, with no concern for how things came to be the way they are. The proper subjects of physics were considered time-

less: one recounted the laws of motion by resorting to symbols and equations, not to such narrative devices as foreshadowing and denouement. Gravitation stood outside history; it would always be the same. Of course, the passage of time played an important role in such individual phenomena as the fall of an apple or the heating of a kettle, but not in the grand laws that governed such events.

The absence of history was particularly evident in the study of elementary particles, which began in the twentieth century. The goal of this research was to identify the ultimate building blocks of matter, measure their properties, and discover their modes of interaction. Everything anyone wanted to know about an atomic particle could be represented as a number. In the study of matter, it seemed, Plato had won out over Isocrates.

Now things have changed. During the past ten years or so, elementary particle physics has merged with cosmology, the study of the structure and evolution of the universe. Official acknowledgment of the union came in 1982, when the *Review of Particle Properties*, the bible of high-energy physicists, included for the first time results derived from astrophysics and cosmology, a practice sure to grow in the coming years. This collaboration between the science of the unimaginably small and the science of the incomprehensibly large has even made its way into popular literature, as well, via a small avalanche of books begun in 1977 by Steven Weinberg's *The First Three Minutes*, in which the Nobel laureate described the brief but formative opening act of the universe. Among the many outcomes of this union is one that is no less remarkable for being overlooked: the study of matter has become a natural history. Physicists have discovered that there is a story to matter, a story in the true sense of the word, with a riveting beginning, a middle rich in detail and bristling with surprising subplots, and a suspenseful ending.

James Clerk Maxwell, the nineteenth-century physicist who invented the theory of electromagnetism, once remarked, "It is when we take some interest in the great discoverers and their lives that [science] becomes endurable, and only when we begin to trace the development of ideas that it becomes fascinating." In this astonishing admission, one of the world's masters of abstract reasoning demonstrated that he, like the rest of us, was seduced by stories. What Maxwell had in mind could not be found in physics itself at that time but only in the history of physics. That's where the stories were.

The history of physics, of course, is not to be confused with the history of matter. The history of physics—or of any science—is a discipline unto itself. Its practitioners are historians rather than scientists; its methods and aims are as different from those of physics as a library is from a linear accelerator. The history of matter, by contrast, implies a built-in historical component; the quality of temporality is to be found in the object of scientific inquiry rather than in the development of the discipline itself.

The best-known example of a science with a built-in history is evolutionary biology. At about the same time that Maxwell was composing books in the language of calculus, Charles Darwin was writing his revolutionary theses *On the Origin of Species* and *The Descent of Man* in ordinary English. They can be read as literature even though they are works of professional biology; literary devices—digressions, subplots, embroideries—abound. Who can resist being fascinated by Darwin's entertaining tales of the engineering skills of bees, the love antics of bowerbirds, or the horrors of infanticide among the Polynesians?

But more important than the literary appeal of the genre was the introduction of history into biology. Before Darwin, biology was dominated by taxonomy, the static science of classification. Reinterpreted according to the theory of evolution, taxonomy acquired a dynamic, and classification was made to submit to the laws of lineage. By introducing the dimension of time, Darwin's theory connected a multitude of disparate taxonomic observations into a logical sequence of development, just as the trunk, branches, and twigs of a tree connect its leaves. A similarly significant shift occurred in geology with the advent of plate tectonics. Whereas the surface of the earth was once regarded as a stationary mosaic of landmasses and oceans, it is now understood to be a dynamic system in perpetual, turbulent change, a system whose history can be read in the rocks that exist today.

In recent years, physicists have found signs of impermanence in their own domain as well. Of course, no one has ever suggested that matter, in the superficial sense, is invariable. Food is digested, gas burns, trees grow; the study of such transformations is the business of chemists and biologists. But the substrate—the atoms that make up the pepper steak, Exxon unleaded, and the Douglas fir—was long considered immutable. And with the exception of certain rare and violent phenomena (radioactive decay is one), this view was correct, at least regarding geologic time. To a chemist or a geologist, anything that keeps the same identity for six hundred million years—say, a normal atom of carbon—is for all intents and purposes immutable. But by dint of their concern about fundamental questions of origin, the cosmologist and the elementary particle physicist are inclined to take a longer view; turning back the clock to nearly the beginning of the universe, they have found that the carbon atom led a quite different life before it entered its present period of stability.

The evidence from which this story has been woven consists of a vast collection of data from such sources as computer simulations; experiments with particle accelerators; and astronomical observations with radio telescopes, balloon-borne cosmic ray detectors, and space probes. The carbon atom, for example, was constructed from three helium atoms in the interior of a star and then flung into outer space when the star exploded, long before the birth of our solar system. The helium, for its part, had been synthesized from hydrogen, either in the same star or in the big bang with which the universe began fifteen billion years ago, and the hydrogen, in turn, from quarks. Indeed, most of the drama in the story of matter is compressed into the opening moments of the universe, an episode so brief that it was overlooked altogether by earlier physicists.

Today we know what we would find if we could travel backward through that inaugural episode: When its age could be measured in minutes, the universe was bathed in light. Before that, it had been like the core of a hydrogen bomb—an inferno of cooking helium. The helium had condensed from a scalding soup of protons and neutrons that, in their turn, had been forged from quarks. Ever closer to the beginning of everything, we would find a mixture of equal parts of quarks and antiquarks, of matter and antimatter, and finally—when the universe was less than a nonillionth of a second old—a world in which the term *matter* ceases to have meaning because all the elementary particles we know (including quarks, antiquarks, electrons, positrons, muons, tau leptons, neutrinos, vector bosons, gluons, even particles of light) were continuously and rapidly changing into one another in a formless hurly-burly.

As a dramatic story, this three-minute epic rivals the Book of Genesis and other creation myths. But just as history is more than a descriptive discipline, the story of matter is more than an entertaining yarn; an understanding of the past and present nature of matter, and the physical laws that govern relationships between the two, allows one to use history as a tool for both analysis and prediction.

A good illustration of analysis is the way that knowledge of matter's history contributes to an understanding of neutrinos. These ghostlike particles, produced in certain radioactive decays and in the collisions of nuclei in the sun and other stars, flit about the universe in immense quan-

Back, by popular demand.

Just a few years ago, illegal hunting and encroaching civilization had all but destroyed the alligator population in the south. They were added to the official list of endangered species in the United States.

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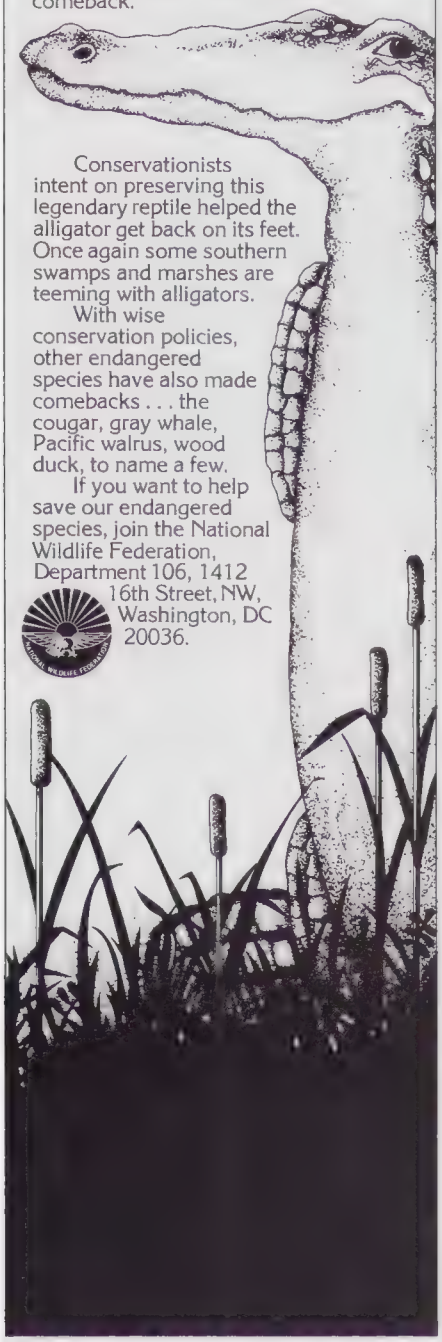

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tities but don't appear to contribute to the constitution of matter. Until recently, one might have imagined the world little changed by their loss, just as one might imagine the world remaining more or less unaltered by the absence of mosquitoes. But the history of matter teaches us that the loss of these seemingly inconsequential particles would render the universe unrecognizable.

With the help of particle accelerators, three kinds of neutrinos have been identified. Sorting out the subtle differences among them is a complicated and time-consuming task that occupies hundreds of physicists and is far from complete. But cosmologists have determined that neutrinos were part of the primordial soup of particles that constituted the universe during the big bang. One of the clues to the state of affairs at that time is the amount of helium that can now be observed. Helium accounts for about a quarter of all the matter around us and, after hydrogen, is the most abundant element. The history of matter tells us that the amount of helium in the universe today depends critically on the number of types of neutrinos that have always existed. In view of this connection, helium's share of the total chemical inventory, twenty-five percent, implies that the number of neutrino types is either three or four. If there were more types, the primordial stew would have been richer and hotter, more helium would have formed in the cosmic pressure cooker, and there would be more helium in evidence today. Conversely, fewer types of neutrinos would have yielded less helium than the twenty-five percent found today. Thus, cosmologists are able to say to elementary particle physicists: Maybe you will find a fourth type of neutrino, maybe not. But don't bother to look for a fifth; we are certain one doesn't exist. Knowledge of the history of matter has placed a powerful restriction on the classification of elementary particles.

Whereas cosmological research into the universe's past elucidates questions posed by particle physicists, particle physics, in turn, helps cosmologists predict the future of the universe. Until recently, one of the cornerstones of the study of matter had been the assumption that protons—which, together with neutrons, constitute all the nuclei of all the atoms in the universe—never decay. Modern theories of the interaction of quarks, however, have raised suspicions about the proton's indestructibility. The issue is of no small consequence, since, if protons do indeed decay, all forms of matter—mountains and oceans, the earth and the other planets, stars and galaxies—will eventually crumble into a desolate gruel of neutrinos and electrons. (I'm leaving aside the unpleasant possibility that, before decay occurs, gravitation will stop the distant galaxies in their outward paths and pull them back together again, causing the universe to collapse upon itself in a cataclysmic reversal of the big bang.)

According to current evidence, if protons decay, they do so, on average, after an elapsed time that is longer than the present age of the universe. Whatever the exact lifetime turns out to be, it bears critically on the fate of matter. Not surprising, then, is that the suspected impermanence of the proton is now the focus of experiments the world over.

At the dawn of science, when philosophers began to speculate on the nature of physical reality, physics and cosmology were indistinguishable. Later generations of physicists, increasingly preoccupied with small-scale laboratory experiments of short duration, banished cosmology to a back room in the house of science, where it became a harmless, inconsequential pastime of astronomers. But the exile could not last. Just as an inquiry into the nature of man must concern itself with birth and death, so the study of matter has raised questions about *its* origin and destiny. Physics, in acquiring a historical dimension, has taken a step toward closing a long-standing rift. Equally important, the reconciliation is occurring in a way that is faithful to the teachings of both Plato and Isocrates. ●

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Robert Wright

Diego Rivera, Detroit Industry *(detail of south wall), 1932–33*

Phantom of the Factory

Some sportcasters can make a sloppy, one-sided baseball game seem like athletic history in the making. Some newspaper reporters can turn a town council meeting that climaxed during the pledge of allegiance into three hours of high political drama. Some trend watchers—journalists and academics alike—can spot harbingers of social and cultural transformation at a Daughters of the American Revolution tea. All of these professional observers are attuned to a fundamental truth: there is little money to be made by telling people that nothing special is going on.

Inflated rhetoric has its price, of course. On those occasions when something special *is* going on, trend watchers are pushed by past excess to the outer limits of language. Having called ripples "waves," they must call waves "tidal waves." Witness the names already given to the present period of flux: the micromillennium, the microelectronics revolution, the technetronic era, the telematic society, the wired society, the network nation. My favorite, on grounds of sheer cleverness, is the mediacracy. For convenience, I use the information age; it is no less melodramatic than the rest, perhaps, but it is straightforward, and most people have at least a vague idea of its meaning: the information age is a revolution in work and play resulting from innovations in electronic communication and the coming of the computer.

Or is it? Harvard University Press is about to publish a book by James Beniger, a sociologist at the University of Southern California's Annenberg School of Communication, that may puncture the popular conception of the information age. Not that Beniger sees the information age as unimportant; on the contrary, he argues that, when viewed as an economic, and not strictly a technological, phenomenon, it is a watershed in human history. It's just that he sees it as nothing new. After listing more than fifty labels that have been affixed to the present (including those above), he writes, "Unlike most of the other writers, I do not conclude that the crest of change is either recent, current, or imminent. Instead, I trace the causes of change back to the middle and late nineteenth century." There he sees the seeds of "the control revolution" (the title of his book). And the momentous developments we keep reading about—artificial intelligence, the proliferation of microcomputers, massive communication via satellite—Beniger sees as but additional chapters in that revolution.

I find this view of things a little threatening. If the information age is indeed old hat, then this column might just as topically be called Victorian Update—and might just as well be written by someone other than me. Nor am I alone in being professionally jeopardized by Beniger's book. As the number of catchy synonyms for the information age suggests, trend watchers have turned speculation about the earthshaking impact of information technology into a small but thriving industry. Surely they will agree with me that this book poses a clear and present danger to the material well-being of armchair theorists and self-styled sages everywhere. Surely they will applaud me when I declare that I, for one, am not going to take Beniger's thesis lying down.

Beniger likes to look at the big picture. He not only views the control revolution against the backdrop of human history but steps back further and evaluates its place in the history of life. This perspective succeeds in (among other things) illuminating the role information plays at different levels of organic organization: What does human language have in common with the genetic code, the messages moving along a jellyfish's neural net, and the chemical trails that bind an ant colony? One answer is that all affect the movement of life—and, more often than not, coordinate that movement. Just as the preacher's sermon, the quarterback's audible, the Stop sign, and the rules of Monopoly impose order on the behavior of people, so can simpler instructions, made of only a few molecules, induce a cell or an organism or a bunch of them to behave coherently. At all levels of life, information is influence, communication is control.

Before the control revolution, says Beniger, came the crisis of control, a product of the industrial revolution. The crisis lay in a suddenly energetic economy: During the nineteenth century, the "entire societal processing system, from extraction and production to distribution and consumption," was invigorated by steam power. By the second half of the nineteenth century, raw materials were

being processed with startling facility. Petroleum flowed from refineries, and steel from mills, in unprecedented volume. This hardly sounds troublesome; if a nation in the midst of industrial revolution couldn't use lots of cheap steel and oil, who could?

But, Beniger says, the matter was not so simple. Metal, for example, was assuming more and more elaborate forms; the ingredients of a single sewing machine had to pass "from foundry through tumbling, annealing, japaning... drilling, turning, milling, grinding, polishing, ornamenting, varnishing, adjusting, and testing." The efficient control of such a process was no easy task, and, besides, there were questions of distribution: how to get sewing machines out of warehouses and into shops all across America. The problem wasn't one of transportation per se; trains existed, and train tracks went wherever there were plenty of people to carry. But the system lacked coordination. Freight traveled circuitously; boxcars sat idly. Henry Varnum Poor, editor of the *American Railroad Journal*, wrote in 1854 that "cars in perfect order have stood for months upon switches without being put to the least service, and without its being known where they were."

America in the second half of the nineteenth century, seen from Beniger's point of view, was like a man with immense muscles but an unformed nervous system. It was a bumbling giant of a nation, a mass of unrealized potential: Arnold Schwarzenegger without definition.

Help was on the way. A technology of coordination was budding. Beniger's list of key innovations in control between 1830 and 1939 holds a hundred and fifty items. It includes the obvious: the telegraph (invented in 1838 but only later used to centrally regulate a large train system, the Erie); the transatlantic cable (laid in 1866); the telephone (invented in 1876 and eventually used to lubricate almost every phase in production and distribution). But the list goes well beyond the obvious, too. Through Beniger's paradigm, many things not commonly considered information technology are seen to be instruments of economic coordination: the postage stamp (1852), paper money (1862), the wristwatch (1905).

Indeed, even innovations not normally thought of as *any* kind of technology made Beniger's list. One example is the "shop-order system of accounts," under which each inchoate sewing machine carried a slip of paper charting its path through the labyrinth of production. More pervasive and important was the idea of dividing the labor of processing information—bureaucracy. Though invented millennia ago, it enjoyed sudden growth and refinement during the nineteenth century, as is reflected in a number of information utensils then appearing in offices: blotting paper (1856), the pencil with eraser (1858), carbon paper (1872), and the modern typewriter (1873)—the one with the QWERTY keyboard.

Also part of the control revolution were the mail-order catalogue (1872), the full-page advertisement (1878), and the national publicity stunt (1889). Advertising, after all, is an instrument of control—not just in its insidious manipulation of individual tastes but, more innocently, in the aggregate, as well; by using it to boost and fine-tune the demand for goods, companies can enjoy the efficiencies of large-scale and predictable production.

In short, the industrial revolution created a crisis of control in production, distribution, and demand, and resolution came only with the control revolution: a series of innovations in the way information is passed among people. The revolution continues today. Television shapes demand more powerfully than the full-page advertisement. Department store catalogues are being supplemented in some towns by videotex, which makes mail order instantaneous. And microprocessors overseeing legions of robots orchestrate automated production. Thus does Beniger see the twentieth century's electronics and microelectronics revolutions to be of a piece with the advent of the postage stamp and the telegraph. All fit into a nationwide project—more than a hundred years old, now—to build a nervous system that can master modern industrial muscle.

Arguments like Beniger's are more easily made than backed up. Human history is a messy process, in which causes and effects merge and diffuse with blatant disregard for analytical convenience. Defining eras, and isolating their endpoints, is like trying to find faces in passing clouds. Vindicating those definitions is sometimes as difficult as convincing a psychiatrist that your reading of a Rorschach inkblot is "correct."

For the most part, Beniger supports his argument the way historical arguments are typically supported: he tells a story that renders his point plausible; he lists crisis after crisis, and then solution after solution, in production, distribution, and demand. His story is convincing in the way that such narratives can be convincing, but it must be accorded the skepticism they are always due; a skillful narrator can, by shining the spotlight on the right facts, make history jump through hoops. Fortunately (for Beniger, as least), he has found less suspect support, as well: nice, hard, cold numbers.

The context for Beniger's numbers was set forty-six years ago by the Australian economist Colin Clark, in his book *The Conditions of Economic Progress*. Clark was, like Beniger, a lover of the big picture; he looked for the broadest economic forces, the weightiest trends. One of the trends he saw is arguably the weightiest in all of economics. "A wide, simple and far-reaching generalisation in this field," he wrote, "is to the effect that, as time goes on and communities become more economically advanced, the numbers engaged in agriculture tend to decline relative to the numbers in manufacture, which in their turn decline relative to the numbers engaged in services." (Clark did not take sole credit for this observation but traced it back to 1691, when Sir William Petty, a British economist, wrote, "We may take notice that as Trade and Curious Arts increase; so the Trade of Husbandry will decrease.") Clark thus divided the economy into three sectors, each of which flowers in its turn.

As it turns out, Clark's services sector houses an important subdivision—between services that deal primarily with information and those that don't. For example, plumbers, aside from a greeting, a brief interrogation, and the crafting of an ample bill, don't spend much time handling information. But lawyers, actuaries, accountants, and teachers do. Even doctors spend about half their time as information processors—listening to patients, collecting additional data through direct inspection, scanning memories and books for diagnoses.

Thus, the rise of the services sector masks the rise of a fourth distinct sector: the information sector. The agriculture and manufacturing sectors also include workers who really belong in this sector. Even agricultural conglomerates and manufacturing firms have to handle information, after all. (That is one of Beniger's main points; as companies have grown and become more bureaucratic, they have handled more and more.) For purposes of analysis, paper shufflers of all stripes should also be transplanted into the information sector.

The function of this sector, broadly speaking, is to keep the other sectors running smoothly—to mediate the flow of information that controls the flow of matter and energy in the rest of the economy. If Beniger is right—if the latest information technology is but the tail end of a long, gradual growth of the economy's capacity for control—the information sector should have begun expanding toward the end of the industrial revolution and expanded steadily into the twentieth century, as the nation's industrial muscle found greater coordination.

That is exactly what happened. In 1830, the information sector accounted for less than one percent of the labor force, but in 1840 the figure was four percent. By the end of the century, it had risen to thirteen percent, and in 1930 fully

one-fourth of American workers made their living by handling information. It was in 1960—well before the appearance of the phrase "information age"—that the American economy became indisputably an information economy: the information sector, with forty-two percent of the labor force, edged out the manufacturing sector, at thirty-five percent, to become the largest part of the work force.

Not only had the information economy grown considerably by 1960; it had also just about quit growing. Between 1950 and 1960, its share of the labor force rose from thirty-one to forty-two percent, yet during the next decade that figure climbed only four more points, and further slowing seems on the way. If the estimates for 1980 used by Beniger are correct (recent data of such fine definition are hard to come by), the number rose by less than half a percentage point during the past ten years. The only other time this century it has failed to muster even a one-point gain was between 1930 and 1940, when the economy wasn't changing much in any respect.

The upshot, apparently, is that everybody did indeed miss the boat: the information age didn't dawn on trend watchers until the economic ascent of information had almost ended. How embarrassing: all these books and magazine articles (and columns) are dwelling on news that is somewhere between thirty and one hundred and thirty years old.

But perhaps there's hope yet. It may be that the leveling off of the information sector's growth signals another revolution, in some sense part of the control revolution, and yet, in a way, utterly new. And it may be that it is the first faint stirring of the next revolution, not an echo of the last, that all the talk is really about.

Another information-age book will be coming off the presses this summer, shortly before Beniger's. It extends the work of the late Princeton economist Fritz Machlup, the first person to clearly discern the information economy. In 1962, Machlup's book *The Production and Distribution of Knowledge in the United States* revealed that the knowledge industry (Machlup chose this term over "the information industry" only after some deliberation) was big business. The mass media, the schools, such professions as law, such trades as typesetting—all told, they had accounted for twenty-nine percent of the gross national product in 1958. And it appeared, Machlup wrote, that the figure had been rising for some time. In the wake of Machlup's death (in 1983), two of his associates, Michael R. Rubin and Mary T. Huber, have taken data he was gathering for a multivolume series, updated it, and arrayed it in a book called *The Knowledge Industry in the United States:*

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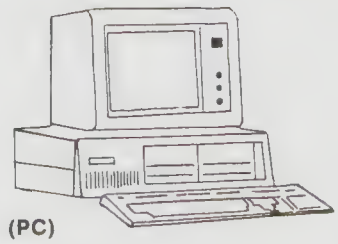

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1960–1980. Their numbers suggest—if only tentatively—that something important is starting to happen.

These data, like Beniger's, show a slowing of growth in the information sector. But they also show the slowing to be uneven. As Rubin and Huber define the information sector, it is populated by four kinds of workers: managers and proprietors (the people who do the paperwork that keeps the McDonald's franchise running); sales workers (car dealers spend most of their time talking, after all, and even manning a cash register amounts to recording exchanges of assets); clerical workers (secretaries, court reporters); and professional and technical workers (doctors, lawyers, engineers, draftsmen, scientists, laboratory workers). As it turns out, the first two of these categories grew as a percentage of the labor force between 1970 and 1980, while the second two shrank. So the question is: What do clerical workers have in common with professional and technical workers? The answer is that both have good reason to fear computers.

Clerical workers face the more immediate threat. Machines long ago began to assume such tasks as numerical computation, but it was only in the late seventies that word processors invaded the office. The invasion has proceeded apace. (And, whereas it once victimized mainly secretaries whose bosses didn't mind typing letters into a word processor, its threat is spreading: IBM recently demonstrated a machine that takes dictation.)

In the professional and technical fields, too, some workers can feel computers breathing down their necks. CAD-CAM systems (the acronym stands for computer-aided design and computer-aided manufacturing) reduce the number of draftsmen, even engineers, required to see some projects through to completion. And if the demand for accountants, lawyers, and doctors has been largely unaffected by computers, it may not remain so for long. One of the more impressive examples of artificial intelligence is INTERNIST, a program that can diagnose some diseases about as surely as the average physician. As for accountants, software now gives in minutes the kind of guidance in financial planning and income tax preparation that once took hours. And for $39.95, you can slip a copy of DiskWILL into a disk drive and receive instant advice on composing your last will and testament. (And this program, unlike a lawyer, will not charge for five minutes of thought devoted, while shaving Monday morning, to your impending death.)

Of course, none of this necessarily means that the sudden slowing of growth in information-sector employment is coming at the hands of computers. Perhaps nothing more is at work here than the difficulty of collecting precisely comparable statistics from year to year. Nor is it certain that many white-collar workers stand in imminent danger of losing their jobs to machines; much of the promise of artificial intelligence remains unfulfilled. Nonetheless, notwithstanding the continuity that Beniger cogently attributes to the control revolution, an important line was crossed somewhere along the way, and it may turn out to be a great divide.

The line separates information transmission from information processing. During most of the control revolution, innovations in processing have not been technological in the strict sense of the word, but organizational—lying mainly in a rerouting of information flow among humans. To be sure, technology has played a role; the telephone has permitted executives separated by several floors or city blocks or cities to function as if they were standing next to each other on the information assembly line. But the telephone —and the telegraph, the radio, the television, and the satellite—are, by themselves, technologies of information *transmission*. Only in the second half of this century, with the coming of the computer, has the large-scale automation of information *processing* reached the workplace, and only in the 1970s, with the coming of the microcomputer, did it reach workplaces of meager means.

In short, until recently, new information technologies had allowed people to do things they couldn't previously do. But lately, technology has begun to do things people used to do. Or, in Beniger's terminology: during the first phase of the control revolution, humans acquired control of the energy and matter whose movement had been accelerated by machines; during the second, some of that control is being delegated to other machines.

Beniger, of course, is fully aware of the distinction between transmission and processing, and he knows that much of the latter is now being automated. But he believes that this, too, is old hat. The great divide, he insists, was crossed a hundred years ago, in the 1880s, when Herman Hollerith invented a machine that aggregated data recorded on punch cards. In the census of 1890, the machine proved its worth, cutting tabulation and analysis from nine years to less than seven. By the First World War, various automatic information processors were in use, aiding insurance actuaries and battleship gunnery officers, among others.

Beniger's point is well taken; the technological roots of the computer go back a long way (and so, for that matter, do technological roots in general). Nonetheless, it is not clear that automated information processing had much *economic* impact until the Second World War—at least, not the most elemental kind of impact; machines may have been doing a limited amount of work that people could have done, but they weren't taking away and degrading lots of jobs that people already held. That encroachment had to await other developments: mass production of the programmable computer, and then of the microprocessor. The first gave us a machine that could, in principle, perform any intellectual task. The second provided so many of those machines that just about any curious person could spend his time trying to fuse that principle with practice. Hence, the hacker.

The resultant phase of experimentation is still young. (How many articles about artificial intelligence, or even the software industry, did you see before 1980?) But all around are eerie intimations of our expendability: not just INTERNIST and CAD-CAM and DiskWILL, but also electronic chessboards that can humiliate humans without breaking a sweat, and other ominous toys. This, I think, is what underlies the apprehensive excitement about the information age: for the first time, the man in the street has met the ghost in the machine.

In justifying his depiction of the control revolution as a unified and important phenomenon, Beniger invokes a historical parallel: "Just as the Industrial Revolution marked an historical discontinuity in the ability to harness energy, the Control Revolution marks a similarly dramatic leap in our ability to exploit information." True enough. But what was most important about the industrial revolution in practical terms—in human and political terms—was that, as energy was harnessed, machines began to eliminate some jobs and eviscerate others. So, if artificial intelligence lives up to its billing, it is the second part of the control revolution—an explosive growth in the *automation* of control and a likely displacement of white-collar workers—that will hold the more consequential parallel with the industrial revolution.

Coping with the fallout will be difficult. The tried and true palliatives for automated unemployment, such as a shorter work week, may be less easily applied to white-collar workers. And, even if they are effective, other challenges will arise: How many Americans, in this age of easy decadence, will make wise use of more leisure time? Blessed with questions such as this, political, economic, and social analysts of all stripes—including trend watchers—can rest assured that theirs (and maybe theirs alone) will be a growth industry. ●

ROBERT WRIGHT is a senior editor of THE SCIENCES.

PEER REVIEW

Letters from Readers

ONE MAN'S MEAT

Shame on you for printing the misinformation on nutrition in Marvin Harris's article "The 100,000-Year Hunt" [January/February]. Where did he get the idea that "man was not made for a diet of high-fiber, meatless meals"? From his teeth to his anus, man has all the earmarks of a vegetarian. His teeth are grinding molars, not sharp cuspids and incisors for tearing flesh, and his digestive tract is far too long to efficiently process meals of meat.

The problems that arise when humans eat foods of animal origin (milk, eggs, and cheese as well as meat) are not limited to such degenerative illnesses as diabetes, heart disease, cancer, arthritis, and hypertension but include a number of infectious diseases, allergic reactions, and bizarre eating disorders. Our nonvegetarian diet is responsible for three out of four deaths in the Western world, including fifty percent of deaths from heart disease and twenty-five percent from cancer.

Mr. Harris implies that there is no limit to the amount of protein the body can benefit from, but Americans in fact are intoxicated with protein; they consume so much that their bodies produce an overabundance of ammonia and amines, both of which increase the risk of degenerative disease. On the other hand, Mr. Harris apparently thinks one can barely get by on a totally vegetarian diet. In fact, vigor, endurance, alertness, calmness, resistance to disease, slowness to show signs of aging, ability to remain in the workforce, and even the durability of one's teeth all are characteristic of the vegan—the person who eats no animal-produced foods. So it is wrong to say, as Mr. Harris does, that meat is one of the reasons we live longer than our ancestors did. Americans enjoy greater longevity because they live in uncrowded conditions, understand how to protect their bodies from the elements, and have good housing, clean water, vigilant public health agencies, and good prenatal care.

Further, Mr. Harris states that only a very small percentage of the world's human population voluntarily abstains from eating all types of flesh food, but he neglects the fact that less than five percent of the diet of the world's healthiest peoples comes from animal sources and that in many cases this is by choice, as it is for the Tarahumara Indians, of the Sierra Madre, and the Kikuyu tribe, of eastern Africa. In his cause, he cites the Eskimos as healthy people who eat an all-meat diet. Actually, Eskimos take sixty percent of their food calories in the form of fat from animals (whale and seal blubber mostly), not from high-protein muscle.

Mr. Harris should also discard his old-fashioned notion that meat is a better source of protein than plants are. The extra digestive step of disassembling animal proteins to get at the amino acids that came originally from plants is a strain on the human digestive tract. There is a saying from the nineteenth century, when the supremacy of meat protein was a truism: If you wish to be as strong as an ox, eat what the ox eats; don't eat the ox. (None of the protein that nourishes the ox's great muscles comes from meat.)

Mr. Harris also argues that milk and other dairy products are the best sources of calcium, but this is controversial. Because of the high protein, sodium, and phosphorus content of milk, the calcium in it cannot be absorbed by the body as readily as the calcium in, say, broccoli or cabbage. One cup of cow's milk has two hundred and eighty-eight milligrams of calcium, whereas one cup of cooked broccoli contains three hundred and ninety-three milligrams.

If all these advantages of a vegan diet are not sufficient to persuade Mr. Harris, the consummate argument remains: when we attain a world population of seven billion humans in the near future, feeding all of them meat will be impossible.

AGATHA M. THRASH, M.D.
Uchee Pines Institute
Seale, Alabama

¶Marvin Harris overlooks an important fact: it is impossible today for all people on Earth to consume American-style meat-centered meals. There is simply not enough land, water, and energy available for the purpose. The American way of eating requires about two acres of cropland and nearly four and a half acres of grazing land for each man, woman, and child. With approximately four billion inhabitants on this planet, feeding everyone meat would require eight billion acres of cropland and seventeen and a half billion acres of grazing land. Yet according to the United Nations, there is less than half that much cropland and pasture in the world. Converting vast new tracts for these purposes would require huge investments of capital that many of the world's peoples could ill afford. Moreover, the conversion of forests to farmland—tropical forests, in particular—would have detrimental ecological effects. Thus, encouraging other peoples to eat as much meat as Americans do can only lead to conflicts all over the earth.

DEBRA WASSERMAN
Baltimore, Maryland

¶Mr. Harris's cleverly presented article ignores some important realities.

There is no absolute nutritional requirement for animal flesh or fat. As millions of healthy vegetarians (including world-class athletes) will attest, the human body runs extremely well—indeed, probably optimally—on a diet free of meat, poultry, and dairy products. All the protein we require is amply supplied through whole grains, legumes, and green vegetables. Rice, wheat, corn, and potatoes contain all the amino acids essential to man. A calorically adequate, balanced vegan diet makes protein deficiency almost impossible, and, as flesh eating becomes ever more hazardous, due both to the inherent dangers of meat's concentrated protein and fat and to chemical contaminants and hormonal poisons, the shift to vegan foods will accelerate.

That Mr. Harris offers the Eskimos' diet of whale blubber and fish as an example for the urban, sedentary American of 1986 is also distressing. The national statistics on heart disease and cancer reveal clearly the grim results of such a flesh-laden diet. No matter what the Eskimos ate while

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TO OUR READERS

The Sciences has won the 1986 National Magazine Award for Essays & Criticism, for three essays by Senior Editor Robert Wright, published in his column, The Information Age. In their citation, the judges praised Mr. Wright's "stylish use of the classic essay form to render accessible the complex issues raised by information technology." The other finalists, selected from a field of one hundred and thirteen entries, were *The American Lawyer, Discover, Harper's Magazine,* and *Vogue*. *The Sciences* was also one of five finalists (selected from eighty-eight entries for its "cool, accessible clarity" and "classic illustrations") in the category of General Excellence, under 100,000 circulation; the award was won by *New England Monthly.*

In the American Association of Museums' 1986 publications competition, *The Sciences* was one of three magazines to win an Award of Merit, for the design of its March/April 1986 issue, with Leon Golub's painting *Interrogations I* on the cover.

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hunting whales, it is becoming clear that flesh eating is an idea whose time should pass. There are now room and food enough for everyone on this planet, but there won't be for long if we continue devoting precious farmland to the production of beef protein when it could produce ten times as much legume protein. The sooner meat eating becomes an embarrassing anachronism, the healthier the world's people and the planet itself will be. For civilized man, the 100,000-year hunt will have ended.

MICHAEL A. KLAPER, M.D.
Eustis, Florida

¶ Marvin Harris asks us to believe that "animal foods are more critical for sound nutrition than are plant foods." The meat, egg, and dairy industries may find his message appealing, but the past fifty years of medical and nutritional research paints a different picture. Throughout human history, meat has been considered a delicacy and consumed mostly in small amounts, on festive occasions; only the rich made every meal a meat-centered feast. Western society has now attained a level of wealth and technology that allows almost everyone to eat like an aristocrat—and look at the results: epidemics of obesity, heart disease, hypertension, diabetes, gout, and cancer, to name a few common diet-related health problems.

Mr. Harris may be an expert in anthropology, but his understanding of basic human nutrition is flawed. To mention just some of the many mistakes in his article: the World Health Organization standard for nutrition states that an adult male needs thirty-eight grams of protein daily, not the sixty grams Mr. Harris reports; humans require eight essential amino acids, not ten; animal foods are severely deficient in vitamin C, contrary to Mr. Harris's contention; and the human body *can* absorb fat-soluble vitamins without taking in fat. He is also apparently unaware of the easily verified fact that chicken and fish contain cholesterol in amounts similar to those in beef and pork.

To his credit, Mr. Harris demonstrates great enthusiasm for his topic. Few people would have invested so much effort in distorting so much information to support such an indefensible point of view.

JOHN A. MCDOUGALL, M.D.
Kailua, Hawaii

¶ That humans can digest fats and cholesterol and that meat is a rich source of protein do not mean that these are healthful foods. Our prehistoric ancestors generally did not live long enough to be stricken with atherosclerosis and heart disease, so selective genetic pressure would not have acted to eliminate meat eating from the diet. Nonetheless, the Western Collaborative Group Study—an extensive analysis of risk factors for heart disease in a group of three thousand people living in Framingham, Massachusetts—showed that increases in blood-cholesterol levels were associated with increased risk for heart disease. Whereas it is virtually impossible to induce atherosclerosis in dogs, cats, and other carnivorous animals (they are genetically programmed to handle meats), omnivorous animals, such as man, are not so well designed to rid their bodies of excess cholesterol. The moral is clear: despite the fact that our ancestors loved meat and that we do, too, it carries with it the danger of heart disease.

MURRAY E. JARVIK, M.D.
Veterans Administration Medical Center
West Los Angeles, California

Marvin Harris replies: Agatha Thrash is mistaken. *Homo sapiens* is neither a carnivore nor an herbivore but an omnivore—a consumer of both animals and plants—and that preference is widely distributed in the primate order (see R. Harding and G. Teleki, *Omnivorous Primates*, Columbia University Press, 1981). Hominid dentition and gut physiology mark us as being adapted for both food types, not for herbivory alone: proportionately large molars, able to grind tough seeds and fibers, are more characteristic of early hominid species than of later ones, and *Australopithecus robustus*, the hominid with the largest molars (and, presumptively, the most vegetarian preferences), was an evolutionary dead end (see my *Culture, People, Nature*, fourth edition, Harper and Row, 1985, for detailed references). The human gut, also contra Mrs. Thrash, lacks such specialized features as the cow's rumen (which digests food partially and prepares it for regurgitation and further chewing) and the horse's enlarged cecum (which largely breaks down food before it reaches the rest of the intestine), as I discuss in chapter four of my book *Good To Eat* (Simon and Schuster, 1985). Thus, Mrs. Thrash seems oblivious to the physiological barriers that prevent us from eating what the ox eats. Alas, even the most zealous vegan cannot live on grass alone.

Mrs. Thrash's claim that Americans are "intoxicated" with protein cannot be squared with the fact that the steady increase in consumption of animal foods in the United States and other industrial nations has been accompanied by a steady increase in life expectancy. Of course, this correlation does not prove that there are only beneficial consequences associated with an increase in animal-protein consumption. But if there are adverse effects, they have not been adverse enough to prevent the rise in life expectancy. This casts doubt on the notion that we are being poisoned. Furthermore, there is a

growing body of evidence (not referred to in my article), based on osteological criteria, that when humans made the change from hunting and gathering to agriculture, there was, in both the Old and New worlds, an increase in signs of poor nutrition and a decline in the average age of death (see M. Cohen and G. Armelagos, *Paleopathology and the Origins of Agriculture*, Academic Press, 1984). One can say at least that if grain-based diets were beneficial, they were not beneficial enough to prevent a decline in longevity.

Though Mrs. Thrash offers the Tarahumara and the Kikuyu as remarkably healthy examples of voluntary vegetarians, neither group practices what she preaches, nor do they exhibit enviable mortality rates. Shortages of arable land oblige the Tarahumara to preserve most of their livestock so they can have as much dung as possible for fertilizer. Yet these conditions do not prevent them from sacrificing and eagerly consuming their goats during curing and calendrical rituals. Their taste for meat extends to birds, squirrels, and deer, which they regard as delicacies and hunt remorselessly. As for the health of these supposedly voluntary vegetarians, "childhood mortality... runs more than fifty percent" (J. G. Kennedy, *Tarahumara of the Sierra Madre*, AHM Publishing, 1978). The Kikuyu (of Mau Mau fame), like most East African pastoralists, do not slaughter cattle except for occasional meat feasts (for reasons explained in chapter three of *Good to Eat*). But they regularly consume significant numbers of sheep and goats in connection with births, deaths, marriages, and religious festivals. Their consumption of cow's milk is proportional to the number of cows kept (see J. Kenyatta, *Facing Mount Kenya: The Tribal Life of the Gikuyu*, Vintage, 1962), and Kikuyu warriors used to open the jugular veins of cattle and drink the blood (see J. Middleton and G. Kershaw, *The Kikuyu and Kamba of Kenya*, International African Institute, 1965). Some vegetarians! As for the Eskimos, my point was that they were healthier when their diet consisted of meat and animal fat than when they depended more on carbohydrates. What proportion of fat they consume relative to meat is irrelevant.

Finally, standard food-value tables do not support Mrs. Thrash's assertion that broccoli is a better source of calcium than milk is. A hundred grams of whole milk contains one hundred and nineteen milligrams of calcium, whereas the same amount of cooked broccoli contains only eighty-eight milligrams (see J. Pennington and H. Church, *Food Values of Portions Commonly Used*, thirteenth edition, 1980, Harper/Colophon).

Regarding Debra Wasserman's letter, my point is precisely that societies lapse into vegetarianism only because animal foods become too expensive for them. The ecological problems posed by meat eating do not arise because Americans "encourage" others to increase their consumption of animal foods. Rather, developing nations will indulge their own well-established preferences for animal foods as long as they can pay for them. Nor does the growth of the world's population mean that we need resign ourselves to the spread of involuntary vegetarianism. Animal husbandry has a vital role in many stable ecosystems; bioengineering can have a bright side as well as a dark.

In view of the nutritional importance of animal foods, ethical considerations would suggest an attempt to increase animal production at least as much as they would prompt passive acceptance of an involuntary vegetarian future. At any rate, the purpose of my article and of *Good to Eat* was not to encourage or discourage particular diets but to explain them. The phenomenon of "meat hunger" is of particular interest because it complicates any attempt to explain why the flesh of such abundant animals as cattle in India, or dogs and insects in this country, is rejected as human food. Such taboos exist *despite* the virtues of animal protein, not *because* of its dangers.

Mr. Klaper's advocacy of a vegan diet is as dangerous as the advocacy of an all-meat-and-blubber diet (which, of course, no one advocates). He seems to believe that large populations are capable of precisely controlling the proper mix of plant foods in their diets, whereas anyone concerned with public health and nutrition is aware that it is a mixture of plant and animal foods that has the best chance of providing realistic safeguards against malnutrition. Moreover, for every potentially dangerous consequence of eating too much fat, there is at least one potentially dangerous consequence of overconsuming plant foods, ranging from anemias caused by plants' chemical compositions to slow poisoning associated with the imperfect processing of manioc to the sudden death that fava beans and other potentially toxic plants can cause.

In his zeal to stamp out the consumption of flesh, Mr. Klaper forgets that the farmlands he wishes to rescue are not the sole source of animal foods. Millions of the world's acres are unsuitable for agriculture but are fit for browsing and grazing animals. What's more, the largest part of the earth's surface does not even consist of dry land. In the name of what scientific or humanitarian principle would he have a hungry world abandon the exploitation of the fishes that live in the sea?

Mr. McDougall's claim that meat has been consumed in only small amounts throughout most of human history ignores a half-century of anthropological, ethnographic, archaeological, and paleontological research. He could catch up with these fields by reading the article in *The New England Journal of Medicine* on which I have relied for my estimates that paleolithic meat consumption was many times greater than per capita meat eating in this country last year (S. Eaton and M. Konner, *NEJM*, Vol. 312, No. 5).

Mr. McDougall should also check his "facts." In 1982, the advisory committee to the World Health Organization and the Food and Agriculture Organization voted to raise protein standards by thirty percent, from .57 grams to .75 grams of mixed dietary protein for each kilogram of adult body weight. Publication of the revised standard is expected this year. My source is Peter Pellet, of the department of food science and nutrition at the University of Massachusetts (see "Problems and Pitfalls in the Assessment of Human Nutritional Status," in *Food and Evolution*, edited by E. Ross and me, Temple University Press, in press). This change in standards was anticipated by the ninth edition of the National Academy of Sciences' *Recommended Dietary Allowances*, published in 1980, which, on page 46, also increased its previous mixed-protein recommendations by thirty percent, to eighty grams of protein a day for each kilogram of body weight. Since the hypothetical man in my article weighs eighty kilograms (one hundred and seventy-six pounds), the latest standard for him is, as I stated, "about sixty grams of protein a day," and not thirty-eight grams, as Mr. McDougall would have it.

His information concerning the number of essential amino acids is also incorrect. As of 1980, eight amino acids were regarded as unquestionably essential—indispensable in the diet because they cannot be synthesized by the human body. They are isoleucine, leucine, lysine, methionine, phenylalanine, threonine, tryptophan, and valine. The status of two additional amino acids, histidine and arginine, was regarded as equivocal for adults, though the importance of histidine for children was generally accepted (see P. B. Reed, *Nutrition: An Applied Science*, West, 1980). Subsequent research has strengthened the case for the essentiality of histidine for normal adults as well (see W. J. Visek, "An Update of Concepts of Essential Amino Acids," *Annual Review of Nutrition*, 1984). The status of arginine remains more problematic, but there is much evidence, from both human and nonhuman subjects, that the capacity of the body to synthesize this substance is weak and easily disrupted or reduced by a variety of common conditions, including hepatic disorders, Reye's syndrome, enzyme deficiency states, and breast feeding. So, my statement that there are ten essential amino acids was informed by the latest research; it is a prudent assessment

of dietary needs. Mr. McDougall's number—eight—is not informed, correct, or prudent. And to make matters worse, his tone is uncivil.

Mr. Jarvik's comments are informative and generally corroborative of my argument, though I cannot accept his contention that natural selection merely failed to select against meat eating. Genetic selection established the capacity for meat eating as part of human omnivory. It is as natural for humans to eat meat as to eat plant food. On the other hand, natural selection, by definition, has acted neither for nor against the consumption of the kind of meat we eat today. Game meat has fewer saturated fats (which have been linked to cholesterol) and more unsaturated fats (which have not). The prudent course is not to abandon meat eating but to remove the excess cholesterol and saturated fats that have been bred into food animals during the past few centuries.

THE MAGNUS EFFECT

Hans Christian von Baeyer, in explaining the aerodynamics of baseballs and other beneficiaries of Bernoulli's principle ["Magnus on the Mound," January/February], threw your readers a curve when he wrote that a sailboat travels fastest when the wind is directly behind. A sailboat moves because air pressure on one side of its sail is greater than on the other, creating lift. So, a sailboat attains its greatest speeds on a slightly upwind heading: at an angle of about fifty-five degrees from the direction of the wind, or, in sailing parlance, a close reach. If Mr. von Baeyer's explanation were correct, sailboats would not be able to travel upwind at all.

His statement that "faster" steamships drove the sailboat out of commerce also deserves comment. Boats whose hulls cut through water—that is to say, virtually all boats except hydrofoils—are limited in the speed they can attain by the resistance of the waves they themselves create. Above a certain speed, resistance increases in proportion to the boat's velocity to the fifth power. So, steam driven or sail driven, all boats have the same maximum speed, known as the hull speed. The drawback of sailing vessels, of course, is that they can attain hull speed only when the wind blows.

SCOTT GARREN
Brookline, Massachusetts

¶I was pleased to see Hans Christian von Baeyer's explanation of the effect named for my great-grand uncle Heinrich Gustav Magnus. Mr. von Baeyer introduces Magnus as a chemist (presumably for his discovery of the transport of oxygen in the blood and of a complex platinum compound that bears his name), but he was in fact a professor of physics at the University of Berlin, and most of his work was in that field. He discovered that (and explained why) a fine dust of metallic iron ignites spontaneously at room temperature. And he was the first to investigate systematically the thermoelectric effect —research that offered many more practical applications than the Magnus effect.

WILHELM MAGNUS
Courant Institute
New York University
New York, New York

¶In addition to the Magnus effect described by Hans Christian von Baeyer, and the Lorentz force that drives electric motors (to which he alluded), there are a number of other interesting "counterintuitive" forces in nature. One is the Coriolis effect, which creates weather patterns by ensuring that the winds of the Northern and Southern hemispheres move in opposite directions. Another is the force that impels a spinning top. In fact, the top teaches the best lesson in counterintuitive motion. Push a top, and it will move at right angles to both the direction of your push and the orientation of the axis around which it spins. In other words, it will go sideways.

The common denominator of both of these forces is the presence of an axis around which something spins. Such forces find their mathematical expression as the cross product of two vectors, an apt name for the representation of motion in an unexpected direction.

MANFRED R. SCHROEDER
Universität Göttingen
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¶As every sailor knows, a typical keel sailboat reaches its fastest speed on the beam reach, that is, when it moves perpendicularly (at ninety degrees) to the wind. With a breeze of ten knots blowing, such a boat will reach a speed of seven to eight knots. (A catamaran, at about a hundred and ten degrees to the wind, will sail faster than the wind blows, because its twin hulls riding lightly on the water create less drag than the keel of a regular boat.) The aerodynamics of running (downwind sailing) are different, and the efficiency of the sail under these conditions much lower. With a ten-knot wind, a keel boat will sail downwind at a speed of only about five and a half knots.

MICHAEL T. KOPETZKY
Texas Tech University School of Medicine
Lubbock, Texas

THE MICROWAVE DEBATE

Ross Adey's review of my book, *The Microwave Debate* ["The Energy Around Us," January/February], fails to recognize any distinction between the conduct of science (research into how electromagnetic radiation affects cells, for example) and the making of policy decisions (setting standards for human exposure to radiation). He read my book as if it were about the conduct of science, whereas it is actually a history of policy making. Scientists are not trained to make policy decisions and therefore should not be relied upon when such decisions need to be made. That is why I have argued for the involvement of nonscientists in the debate over the use and regulation of microwave radiation.

Though Mr. Adey chides both me and Robert O. Becker (whose book *The Body Electric* was also reviewed) for believing that "political forces" may be shaping the microwave debate, he himself has complained about such forces. In 1983, commenting on a draft of the book *Nonionizing Radiation: A Case for Federal Standards*, he wrote, in a letter to the book's author, Jane M. Clemmensen:

> The time is long past when legislative and regulatory bodies should turn to instant experts for needed information and advice. As a group, the engineering profession has not only assumed that it is their prerogative to exercise this function, but have also drawn together in public and private enclaves with the specific purpose of deriding and denigrating an ever increasing body of biophysical knowledge that has pointed the way to an appropriate understanding of the effects of low level fields.

As a "member of the biophysical community," Mr. Adey continued, he was "no longer interested in accepting the dictation of engineers who continue to blunder into biology as though it was something they could fully understand at the level of their high school or junior college experience." The same might well be said of scientists who blunder into the fields of public policy and history.

The long list of potential electromagnetic hazards notwithstanding, Mr. Adey attempts to argue that "prudence in long-term human exposure" to electromagnetic radiation is being ensured and that "science will continue to unravel these problems." Purely scientific research is perhaps unraveling purely scientific problems, but at present the policymakers are at a standstill. Despite years of trying, no government agency has yet set a standard to regulate the public's exposure to radiofrequency and microwave radiation. The public needs to understand that its government has given it no guidance on how much exposure to microwave radiation is safe. My book attempts to explain why this situation has arisen, as an aid to public decision making. It is not about the science of electromagnetic effects on organisms and should not be read, or have been reviewed, as such.

NICHOLAS H. STENECK
University of Michigan
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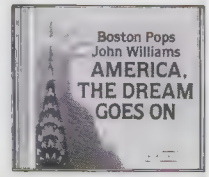

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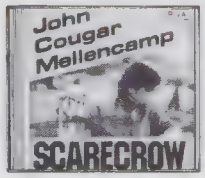

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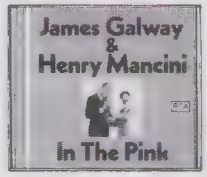

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WHO'S MINDING THE MISSILES?

Too Often, People with Drug, Drinking, or Psychiatric Problems

by HERBERT L. ABRAMS

On May 26, 1981, the day after Memorial Day, an EA-6B Prowler jet crashed into the flight deck of the nuclear aircraft carrier *Nimitz* off the southern coast of Georgia. The plane burst into flames in a tragedy in which fourteen young men lost their lives and forty-four others were injured. In addition, the crash destroyed four fighter aircraft and damaged sixty others, at a cost of more than two hundred million dollars. It was the worst accident in the history of U.S. peacetime naval aviation.

Three weeks later, New York's Democratic congressman Joseph P. Addabbo, who chaired the House Appropriations Subcommittee on Defense, informed the press that many of the marines and sailors killed had had traces of drugs in their systems. In a letter to Navy Secretary John F. Lehman, the congressman wrote, "If any of the air operations personnel on board the *Nimitz* were under the influence of drugs at the time the Marine EA-6B made its final approach, it would be tantamount to a death sentence for those in the aircraft as well as those on the flight deck." The navy replied that Addabbo's information was inaccurate. "I can categorically state," Secretary Lehman said, "that drug use or abuse did not contribute to this tragic crash."

Only two days later, however, the navy conceded that six of the fourteen men who died on the *Nimitz* had been marijuana users, and that at least three of them had smoked it heavily or shortly before the crash. Nevertheless, Lehman said the crew's use of marijuana in no way established "that any of these men were impaired in the performance of their duty"; he insisted instead that the crash had been caused by "pilot error."

Ironically, he may have been right. An autopsy revealed that, at the time of the crash, the pilot of the EA-6B had six to eleven times the recommended level of the antihistamine brompheniramine in his system. He had been taking the prescription drug without the military's approval. A congressional committee looking into the accident concluded that the effects of the medication—which, at such a level, can cause sedation, dizziness, double vision, and tremors—together with other stress factors, probably precipitated the pilot error that caused the crash. The investigation also revealed that, among naval personnel in general, twenty-eight percent habitually used amphetamines.

The extent of drug use uncovered in the investigation would be alarming even if it were exceptional. But several government studies have found drug abuse to be widespread throughout the armed forces. This situation assumes special importance in light of a 1982 report by an investigative arm of the House Appropriations Committee indicating that many of the military's drug incidents and arrests have involved personnel responsible for controlling and maintaining nuclear weapons. Indeed, numerous investigations, surveys, and anecdotal accounts suggest that personnel charged with handling the nuclear weapons of both the United States and the Soviet Union—individuals whose stability and reliability we depend on—frequently suffer from drug or alcohol abuse or psychiatric problems.

In this age of nuclear terror, we all hold out a hope: that no U.S. or Soviet leader, understanding the annihilation that would result from an all-out nuclear exchange, would embark on such a path by design. The hope is probably well founded. Nuclear war, if it comes, is far more likely to be unintentional, to result from miscalculation or misunderstanding. The accidental launch of a nuclear weapon during a period of international tension could trigger an escalation of hostilities and even all-out nuclear war. Why, then, are we entrusting nuclear weapons to people who may be unstable in times of crisis?

About one hundred and twelve thousand individuals are involved in handling America's nuclear arms. Most are responsible for strategic nuclear weapons—long-range weapons for a war waged on Soviet and

Michael Ansell, Mutual Deterrence, *1983*

American territory—including the air force's land-based intercontinental ballistic missiles and nuclear bombers and the navy's submarine-launched ballistic missiles. In addition, about fourteen thousand five hundred army personnel work with tactical or theater nuclear weapons—shorter-range weapons for a war that might be fought on the battlefields of Europe. Widely deployed on the Continent, these weapons include the Pershing 1a missile, the defensive Nike-Hercules surface-to-air missile, and nuclear land mines known as atomic demolition munitions. The Marine Corps maintains no nuclear weapons of its own but during a war would have a variety of navy bombers and short-range army weapons at its disposal.

The U.S. military is deeply concerned about ensuring the psychological stability of its nuclear weapons personnel and takes special precautions in appointing them. The heart of the effort is the Personnel Reliability Program, designed to select competent and reliable persons to manage and control the nation's nuclear arms. The program screens candidates both for "critical" jobs (commanders of nuclear weapons delivery units, pilots and crews of delivery aircraft, and delivery unit personnel with access to and technical knowledge of nuclear weapons) and for less autonomous, "controlled" positions (security guards, storage and supply personnel, and launch personnel in nuclear missile silos).

The Personnel Reliability Program selects only individuals thought to meet a variety of qualifications, such as physical competence, mental alertness, and technical proficiency; dependability and flexibility in adjusting to changing work environments; social adjustment and emotional stability; the ability to exercise sound judgment in an emergency; and a positive attitude toward nuclear weapons duty. The initial screening procedure includes a security clearance and a background investigation into the individual's personal and professional activities and affiliations, including a check of police records, former teachers, employers, and personal references. Then the candidate's personnel files are reviewed, and he receives a medical evaluation. He is also briefed on the workings of the Personnel Reliability Program.

More telling than what is included in the screening process, however, are the omissions. No psychiatric interview or psychological testing is required, and if up-to-date medical records are available, the candidate need not have a physical examination. Further, because of the secrecy that surrounds many assignments, even when a review of the records suggests that a medical examination is essential, the examining physicians may have little knowledge about the position for which they are screening the candidate. The medical records of the candidate's family—which might contain information about psychiatric problems, alcoholism, or a history of drug abuse—are not reviewed.

Once a candidate is appointed, no one from the Personnel Reliability Program follows up to ascertain that he is carrying out his job adequately. Instead, the appointee's superiors are relied upon to report any unusual behavior, and co-workers are expected to evaluate one another. Needless to say, inertia, camaraderie, peer pressure, and personnel shortages (which create a need for extra hands, however unstable) may hinder honest evaluations.

Independent evaluations of the Personnel Reliability Program are not available; it is not even clear whether the military has conducted such studies. One indirect measure of the program's effectiveness in screening out undesirable candidates, however, is the number of persons appointed through the program who are later decertified—removed from their positions. Program regulations dictate that individuals should be decertified if they are found guilty of negligence, serious civil infractions, repeated alcohol or drug abuse (though an isolated instance of marijuana or hashish use need not be grounds for dismissal), or other aberrant behavior that might lead to unreliable performance. According to Defense Department figures, from 1975 to 1984, some fifty-one thousand individuals were decertified—an average of more than five thousand a year. Given that approximately one hundred and twelve thousand people were appointed to fill nuclear weapons jobs during each of these years, if their average length of service was one year, then five percent of all appointees were ultimately decertified; if service ran two to four years, then anywhere from nine to eighteen percent of personnel were removed from their jobs.

No one can argue, of course, with the wisdom of removing individuals discovered to be unstable. But the high

Michael Ansell, Nuclear Cocktail Party, *1983*

rate of decertification is disturbing because it suggests that there are inherent weaknesses in the Personnel Reliability Program as a screen for stability. Even though the rate seems to be on the decline, more than three thousand personnel were decertified during 1985 alone. So at any given time, thousands of potentially unstable individuals have day-to-day responsibility for handling nuclear weapons.

SINCE the Personnel Reliability Program appears to be an imperfect tool for excluding undesirable job applicants, it would at least be encouraging to know that the pool of people from which candidates are drawn is basically fit. But the military population in general suffers from high rates of drug and alcohol abuse and psychiatric disturbances.

In a 1980 Defense Department survey of fifteen thousand randomly selected military personnel, thirty-six percent admitted to using illegal drugs. Forty percent of the respondents between the ages of eighteen and twenty-five had used marijuana during the preceding month, ten percent had taken amphetamines, seven percent cocaine, five percent hallucinogens, and one percent heroin. In the navy, more than a quarter of respondents under twenty-five admitted they had been "high while working" during the preceding year—half of them on more than forty days. And a 1981 survey of U.S. personnel at military installations in Italy and West Germany found that drugs were used *on duty* by forty-three percent of army personnel, seventeen percent of air force personnel, thirty-five percent of marines, and forty-nine percent of navy personnel. A full sixty percent of the crew of the aircraft carrier USS *Forrestal* used drugs on duty.

Alcohol abuse has also been widely reported. According to the U.S. Naval Safety Center, in Norfolk, Virginia, the effects of alcohol and hangovers played a role in fifteen to twenty percent of major naval aircraft accidents in 1979. Defense Department officials testified before Congress in 1982 that an estimated twenty-eight percent of army personnel and twenty-one percent of naval personnel drank while on duty. The highest prevalence of drinking was reported among senior officers.

During recent years, according to a study by the Research Triangle Institute, in North Carolina, U.S. armed forces have enjoyed a measurable decrease in drug abuse. Nevertheless, the problem remains an urgent one for nuclear forces. In 1982 hearings, a House appropriations investigative subcommittee learned of numerous cases of drug abuse among nuclear weapons personnel. At an army nuclear missile site in West Germany, four battalion members arrested for selling drugs identified one hundred and twenty-five marijuana users within the unit. At the navy's communications relay station in Brawdy, Wales, about a quarter of the personnel involved in sensitive, classified work were found to be drug users. And as recently as last year, fourteen hundred individuals were decertified from nuclear weapons handling because of drug and alcohol abuse.

In response to widespread concern about substance abuse in the armed forces, the Defense Department assured Congress in 1981 that no U.S. military unit had ever been declared noncombat-ready because of drugs or alcohol. But if a unit is fully equipped and manned by personnel with proper skills and training, it could be declared combat-ready even if it had a rampant drug and alcohol problem. The Defense Department reporting system uses the quantity—not the quality—of trained personnel and equipment to define readiness. When its investigative staff surveyed one hundred and sixty-seven U.S. commanders in the United States, Europe, and the Pacific, in 1981, forty-seven percent acknowledged that drug use had produced some decline in readiness.

ANY DRUG- OR ALCOHOL-INDUCED instability in the people chosen to handle nuclear weapons is likely to be exacerbated by the character of the work itself. The isolation aboard nuclear submarines and in nuclear missile silos, unnatural work shifts, and, in times of emergency, the extreme stress of being responsible for nuclear weapons are all likely to affect job performance.

A large body of psychological research has established the severe emotional consequences of prolonged isolation. Don A. Rockwell, a psychologist at the University of California's Davis campus, found in a 1976 study that men subjected to one hundred and five days of social isolation in a special laboratory suffered from abnormally high levels of depression, irritability, and hostility. And

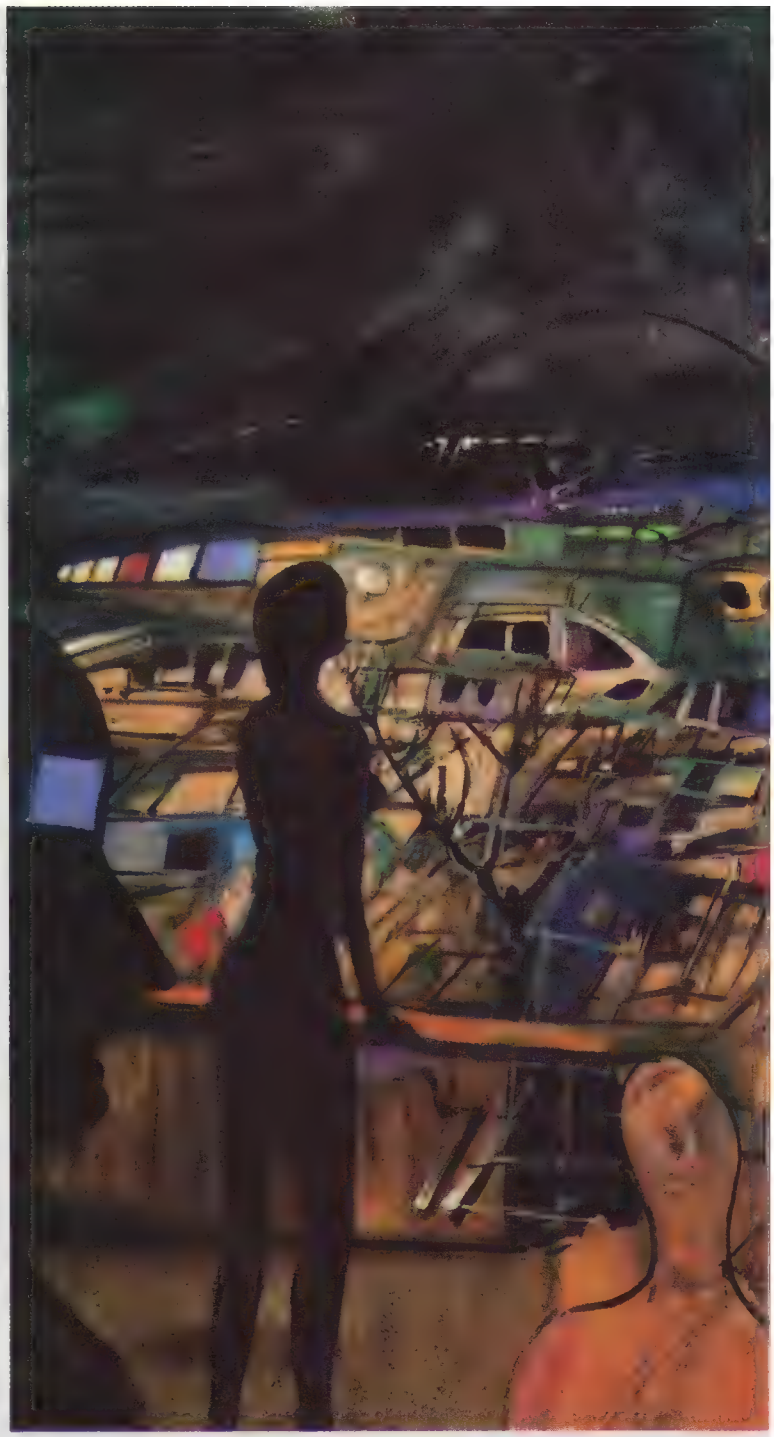
psychologist Irwin Altman and others have reported increased territoriality among socially isolated groups and greater withdrawal from interaction among members of the groups.

Consider the psychological changes that might occur among crews on extended submarine patrols, who face the pressures of leaving family members behind for two or three months at a time, or among members of an ICBM launch crew, who, over a normal four-year tour of duty, serve hundreds of shifts of up to twenty-four hours inside launch control centers. Life in these underground bunkers, with its isolation and inactivity, may induce anxiety and alienation.

Unnatural work schedules cause additional stresses for some military personnel. The routine duties of the navy's nuclear submarine crews are organized around an eighteen-hour cycle, composed of three six-hour shifts. Crew members work one shift, then take twelve hours off before working another. The schedule is not in keeping with the body's biological clock—the internal mechanism that coordinates the hourly release of hormones, sleep–wake cycles, and other physiological processes that follow twenty-four- to twenty-five-hour cycles. Thus, adjusting daily to a six-hour change in work shift is humanly impossible; the feeling is one of perpetual jet lag.

Many investigators have reported high rates of emotional disturbance and impaired coordination among military personnel and civilian employees forced to work when their circadian rhythms dictate they should be asleep. Harvard physiologist Martin Moore-Ede has noted that, in industries with constantly changing round-the-clock work shifts, accidents and errors increase between the hours of three and five in the morning, when normal circadian rhythms are at an ebb. Pilots flying in aircraft simulators make more errors at this time, and the incidence of truck accidents is eight times higher than at other times of day. The accident at the Three Mile Island nuclear power plant occurred at 4:00 A.M.; the workers had just gone on night shift that evening.

The reliability problems posed by violating circadian rhythms would be compounded during a prolonged nuclear alert, with missile crews working double shifts, bomber pilots on sustained airborne alerts, and submarine personnel on duty for extended stretches. Moreover, research on pilot performance suggests that the chances of human error rise sharply during crises. Nazaire C. LeBlanc, of Wichita State University, in a study of personnel responsible for maintaining the Titan II missiles on twenty-four-hour alert, demonstrated that continuous intense stress promotes fatigue and undermines performance.



SIMILAR ON-THE-JOB STRESSES probably are faced by the personnel who handle the Soviet Union's fourteen hundred intercontinental ballistic missiles, six hundred intermediate- and medium-range ballistic missiles, one thousand submarine-launched ballistic missiles, and hundreds of bombers. Although reliable information about the stability of Soviet military personnel is scarce, a few generalizations seem valid.

Abuse of hard drugs appears not to be a major problem in the Soviet Union. The annual death rates from opiates are much lower than in the United States. On the other hand, many soldiers returning from Afghanistan are said to have used hashish and to have brought the habit home with them.

More significant, alcoholism is a problem of epidemic proportions in the Soviet Union. About forty-five thousand Soviets died in 1976 from acute alcohol poisoning—one hundred times the number of victims that year in the United States. Robert B. Davis, a psychologist at the U.S. Army Foreign Science and Technology Center, in Charlottesville, Virginia, reports that per capita consumption of alcohol in the Soviet Union has more than doubled in the past twenty years. Alcohol abuse among the Soviet military, Davis says, is even more common than among

John Hultberg, Apocalypsia, *1971–72*

the population at large. Combined with the widely reported problems of poor nourishment and stressful overcrowding in Soviet military barracks, alcoholism has an inevitable, though undetermined, impact on the reliability of Soviet nuclear weapons personnel. A typical soldier cannot afford state-produced vodka. Many instead drink substitutes, including shaving lotion, varnish, cleaning fluid, antifreeze, brake fluid, shoe polish, and glue. According to one estimate, a third of Soviet military personnel are alcohol dependent, and heavy drinking is said to be especially common among officers.

Accurate information on the psychological health of the Soviet soldier is not readily available. But in a survey of Soviet émigrés who had served in the military, conducted by Richard Gabriel, of Saint Anselm College, in Manchester, New Hampshire, forty-nine percent reported that soldiers in their units frequently went AWOL, and thirty-six percent reported witnessing assaults on officers. Suicide was also said to be common. This kind of violence and insubordination suggests an undue measure of both stress and disaffection, even considering that émigrés may have a strong anti-Soviet bias.

There seems little doubt that a Soviet counterpart to the Personnel Reliability Program exists, though details

about it are kept secret. Soviet officials are clearly aware of the stress to which nuclear weapons personnel are subject, and attempt to select these people carefully. A 1984 article in the Soviet *Military Medical Journal* emphasized the importance of psychological testing in selecting individuals who are intellectually and emotionally able to handle complex and demanding military technology. The current selection process for pilots, for instance, involves examination of an individual's analytic abilities, motivation, capacity to communicate, stability, and many other factors. Those who score high on the psychological tests are much more successful in completing flight training than those with lower scores, and such tests have been used for many years in the Soviet Union.

Still, the Soviet military appears to be afflicted with many of the same staffing problems faced by the U.S. armed forces. For instance, the Soviet navy, despite its prestige, has difficulty attracting sufficient numbers of qualified people willing to endure the strains of long submarine patrols. Thus, whereas the U.S. navy has two rotating crews for each submarine, the Soviet navy maintains only one. The fewer the applicants for such positions, presumably, the lower the selection standards.

EVEN IF IT IS TRUE that rank-and-file nuclear weapons personnel of both superpowers are sometimes undependable, does it matter? After all, there are safeguards to prevent unauthorized launching of nuclear weapons. Wouldn't any launch have to be approved by a top-ranking officer?

In the Soviet military, strategic nuclear forces are commanded by the General Staff, which receives orders on the use of nuclear weapons from the Defense Council and the Politburo. If the General Staff granted release authority, tactical nuclear weapons would fall under the control of the theater command, or directly under the FRONT Command, and both commands would have considerable flexibility in deciding whether and when to use these weapons. A top Soviet military authority observed in 1971 that the "transfer of nuclear weapons to the disposal of strategic, operational, and tactical command echelons gives each great independence and enables them to choose for themselves the means and methods of military operations within the zones of their responsibility and within the bounds of their authority." Although there is strong evidence that most Soviet strategic and tactical nuclear weapons have been fitted with electronic locks to guard against unauthorized launching, the devolution of authority over tactical weapons in the field in times of crisis makes the issue of human instability of paramount importance.

In the United States, as in the Soviet Union, tactical nuclear weapons cannot be as tightly controlled as strategic arms during periods of international tension. Thus, tactical weapons are more vulnerable to misuse by unstable personnel. In crises, commanders might find it essential to give subordinates the authorization codes needed to launch tactical weapons, to avoid delay if the order to fire were issued. Such devolution of control could put hundreds of people in a position to fire such weapons as artillery projectiles and short-range ballistic missiles.

It is true that there are many safeguards in place to prevent the unauthorized use of U.S. nuclear weapons. Most are fitted with "permissive action links" that inhibit the weapons until the proper combination, supplied by the National Command Authority (the president and the secretary of defense), is entered electronically. In addition, before an intercontinental ballistic missile can be fired, a total of four officers at two launch control sites, or capsules, connected to the missile silo must decide individually to launch the weapon. And even after the launch has been ordered, officers in other launch control capsules can issue an inhibit command.

Controls over the firing of submarine-launched ballistic missiles are less stringent. The navy maintains no permissive action links on SLBMs; it argues that, in times of crisis, it cannot be dependent on authorization codes transmitted from Washington because communications could easily be disrupted by, say, the electromagnetic pulse triggered by an atomic explosion. (Critics assert that the navy's refusal to use permissive action links is just a stubborn show of independence.) The captain and crew of a nuclear submarine are supposed to receive higher authorization before firing a missile, but if they should decide to act independently, there are no technical safeguards to prevent them from launching the weapon. Similarly, the crew of a Soviet submarine is supposed to receive approval from both a top military officer and a KGB officer for any missile launch, but no electronic locks or other technical safeguards appear to be in place to prevent an unauthorized launch.

Still, in peacetime, the inadvertent firing of even a submarine-based missile is unlikely, because numerous crew members would have to approve of, and participate in, the launch. The problem arises during crises, when measures to guard against inadvertent launches tend to undermine launch readiness. To ensure that their forces are able to respond rapidly to an attack, commanders on both sides might loosen safeguards—issuing advance authorizations, reducing the number of people necessary for a launch, or partially "enabling" weapons so they could be fired quickly. In doing so, they would open the way for unstable personnel to exert control over nuclear weapons.

Imagine a Soviet submarine captain who, caught in a storm five hundred miles off the Atlantic coast, becomes separated from the Soviet nuclear command and control system during a crisis. Anxious and paranoid, his sense of reality distorted by weeks at sea and perhaps a few shots of vodka, he begins to grow nervous about his ship's safety. He is aware of the international tensions; he knows his country is on alert, as is the U.S. Strategic Air Command. He considers America's preparations for war—its thousand ICBMs and hundreds of bombers poised for attack. As the storm grows worse, and communications cannot be resumed, the captain and his crew begin to feel like sitting ducks. Their missiles are just five minutes from Washington, D.C. They have no permissive action links. What will they do? ●

HERBERT L. ABRAMS is a professor of radiology at the Stanford University School of Medicine and a member-in-residence of the Stanford Center for International Security and Arms Control. His study of nuclear weapons personnel will be published in forthcoming proceedings of an Institute of Medicine–National Academy of Sciences symposium on the medical implications of nuclear war and in a book he is preparing about the danger of unintentional nuclear war.

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THE AUTOPSY'S UNTIMELY DEMISE

Physicians Are Neglecting a Vital Medical Resource

by DANIEL W. MCKEEL, JR.

TO THE PHYSICIAN who first examined the gaunt sixty-eight-year-old woman, the case seemed simple. The patient had arrived at the Washington University Medical Center, in Saint Louis, during the winter of 1981, complaining of fatigue, loss of appetite, and a hacking cough that occasionally produced blood. Her mucus showed signs of infection, and, when X rays revealed a substantial hole in the top of her left lung, the diagnosis was clinched; she was treated for tuberculosis. She took the antibiotics rifampin and isoniazid daily, and within a few weeks her cough subsided.

In the years that followed, the woman received repeated X rays and even a CAT (computerized axial tomography) scan to check the condition of her lungs. Oddly, the lesion kept growing larger, but the diagnosis was not altered. Then, suddenly, this past winter she started to suffer seizures and memory lapses and became acutely depressed. She was admitted to the hospital and, within two months, died.

May H. Lesser, Sagittal Series, *1974*

Autopsy revealed that the patient's left lung had been beset by a large, malignant tumor. As the tumor outgrew its blood supply, it had shriveled, leaving the cavity so apparent in the X rays and CAT scan. Then the cancer had spread, through the bloodstream, to several sites in the brain. Nowhere was there evidence of tuberculosis.

Too often today, the judgment of physicians is clouded by a myth: the belief that, thanks to modern medical technology, clinical diagnosis is nearly infallible. In truth, doctors often misdiagnose disease. A seminal study by the internist Lee Goldman and his colleagues at the Harvard Medical School, published in 1983 in *The New England Journal of Medicine,* reviewed data from three hundred randomly selected autopsies performed since 1960, and discovered a twenty-two percent discrepancy between clinical diagnoses and postmortem findings; in almost half of these cases, a correct diagnosis might have led to different treatment and prolonged survival. Most disturbing, the rate of misdiagnosis did not change from 1960 to 1980—despite the advent of sophisticated laboratory tests and such diagnostic technologies as laser endoscopes, CAT scans, and other ultrasonic and electromagnetic imaging equipment.

Because it exposes diagnostic errors, the autopsy is an invaluable tool for counteracting the dangerous myth of diagnostic perfection, as well as for educating physicians and maintaining quality control in hospitals. Sadly, however, it is a learning experience on the decline. The number of autopsies performed in the United States has been dropping precipitously for twenty years; the percentage fell from forty-one in 1965 to only fourteen in 1984. Though this pleases many clinicians—who are requesting ever fewer autopsies—it is a serious threat to the quality of medical care in this country. The autopsy is in eclipse, and the American patient is paying the price.

THOUGH THE ORIGINS of autopsy might be traced as far back as the twelfth century B.C., when Sumerians examined the entrails of animals to divine the future, the dissection of human corpses seems

May H. Lesser, The Dissection, *1974*

to have begun with the Egyptians some nine hundred years later. The ancient Greeks also performed postmortems; it was they, in fact, who dubbed the practice *autopsy* —to see for oneself—though they used the technique, as did most ancient peoples, not to confirm diagnoses of disease but to study human anatomy. Most ancient civilizations did not make the connection between illness and anatomical disturbances but ascribed sickness to magical causes or to inauspicious mixtures of the four body humors. Only in the second century A.D. did the Greek physician Galen link disease with visible pathology in the body, paving the way for the modern autopsy.

Despite this breakthrough, few autopsies were performed before the end of the Middle Ages, because Catholic and Jewish orthodoxies both objected to human dissection. As religious opposition waned in Europe, with the advent of the Renaissance, the autopsy came to be performed routinely to ascertain the causes of deaths. Postmortem examinations were often superficial compared with modern ones, however, as Lester S. King and Marjorie C. Meehan have noted in "A History of the Autopsy," in the November 1973 issue of the *American Journal of Pathology*.

Then, in the eighteenth century, the Dutch physician Hermann Boerhaave made a major contribution, by stressing the importance of the correlation of autopsy findings and clinical histories. It was this link between living symptoms and postmortem findings that transformed the autopsy into a powerful tool that enabled physicians to describe and diagnose hundreds of diseases.

The first half of the nineteenth century was the heyday of the autopsy: pathologists, using the newly invented microscope, witnessed disease at the cellular level for the first time; the French physiologist Marie-François-Xavier Bichat founded the field of histology—the microscopic examination of tissues as opposed to gross (naked eye) anatomy; and the Austrian pathologist Karl von Rokitansky performed more than thirty thousand autopsies. But perhaps the greatest boon to pathology occurred with the French concept of hospital medicine—a tradition, King and Meehan noted, that extended the notion of correlating clinical and postmortem data, by holding that a single physician should follow a patient closely through life and perform the autopsy at death. Great physicians and surgeons, Sir William Osler and Harvey Cushing among them, continued this practice well into the twentieth century.

In modern times, of course, medicine has become highly specialized; still, close communication between the clinician who treated a patient in life and the pathologist who performed the postmortem remained, until recently, commonplace. Such cooperation was encouraged by the Joint Commission on Accreditation of Hospitals, which required that autopsies be performed in at least twenty percent of all hospital deaths, as a check on the accuracy of clinical diagnoses. This quota was abolished in 1970, thereby permitting hospitals to set their own autopsy rates. But by 1983, so few autopsies were being performed that the American Medical Association adopted a resolution calling for increased use of the procedure in medical schools. The resolution was sponsored by residents and students who believed that gaining greater exposure to postmortem information about the causes of death, the effectiveness of treatments, and the manifestations of disease was crucial to their training.

Such institutional support for the autopsy appears well founded; many studies have shown that postmortem examinations frequently uncover new information. Most recently, a 1984 study sponsored by the College of American Pathologists Foundation discovered that twenty percent of two thousand autopsies performed around the country turned up findings at odds with clinical diagnoses. Diseases frequently misdiagnosed included such common causes of death as heart attack, pneumonia, stroke, and certain cancers; clinicians typically missed a quarter of all lung cancers and two-thirds of all pulmonary emboli (blood clots in the arteries feeding the lungs).

GIVEN THE STATISTICAL EVIDENCE for the value of autopsies, and the historic and institutional support behind the practice, why is the use of autopsies on the decline? Physician resistance is largely to blame. In these litigious times, many doctors worry that autopsies will only increase their malpractice liability. Their fears, however, are not well founded.

It is true that autopsies at times uncover mistakes: misplaced pacemaker catheters that have perforated heart walls; syringe needles left in body cavities; cardiac valves accidentally sewn shut; fatal conditions overlooked. In cases in which a hospital's medical staff was at fault, and was practicing substandard medicine, families of the deceased can initiate and win lawsuits. Far more often, however, autopsies protect the physician by providing objective evidence of the inevitability of the patient's death. A typical case occurred recently at the Washington University Medical Center. An obese man, about to undergo surgery, suddenly had difficulty breathing. When doctors slid a tube down his throat to deliver air to his lungs, blood began to gush from his mouth, choking him, and he died. His family contacted a lawyer about suing the hospital. But when autopsy revealed that both the planned surgery and the intubation had been necessary attempts to save the patient's life (he was found to have had a severe ulcer and several pulmonary conditions, including emphysema, bronchitis, and fluid in the lungs), the matter was settled out of court. Unlike many physicians, hospital administrators and legal counsel appreciate the value of the autopsy in malpractice defense.

Physicians may also be reluctant to request an autopsy out of the desire to put the patient out of their minds and to deny that the death has occurred. Most physicians will not admit to such feelings, however; instead they rationalize their dislike of autopsies, and the rationalizations can be quite convincing. Often physicians attribute their reluctance to request an autopsy to the family of the deceased. Hospital bylaws generally require physicians to seek autopsy permission from the family in every hospital death. At the Washington University Medical Center, twenty-seven percent of the families of adult patients and fifty-five percent of children's families grant permission. But because many individual doctors have far lower success rates in gaining permission, one can assume only that they are not asking the families properly. "You don't want an autopsy, do you?" is a common approach—and one not likely to elicit a positive reply.

Physicians also rationalize their dislike of autopsies by

May H. Lesser, Neuroanatomy, *1974*

claiming that the postmortem yields only esoterica, information of interest to pathologists and physicians-in-training but of little value to clinicians who care for living patients. An autopsy, the argument goes, may reveal previously undiscovered pathology, but if the problem did not manifest during life, it was of no relevance to patient care. This philosophy, shared even by some pathologists, overlooks the fact that new insights into disease, even latent disease, can lead to improvements in health care. Through autopsies, for instance, we have learned that four-fifths of men over the age of eighty have microscopic cancer of the prostate gland. Though in most cases the cancer goes unnoticed during the patient's life and plays no role in his death, the knowledge that this occasionally fatal cancer is so prevalent in older men has taught doctors to include a prostate examination in all physicals of men over age forty. As a result, the number of prostate cancers detected early enough to be treated has doubled in the past twenty years, and since surgical treatment when the cancer is still small almost always leads to a cure, many thousands of lives a year have been saved.

ANOTHER CHARGE physicians commonly level against autopsies is that both gross and microscopic analyses of organs, the traditional mainstays of postmortem examination, lack sophistication and, by implication, value in today's high-powered medical environment. It is true that the majority of autopsies involve only visual examination of the body and its organs and inspection of tissues with a light microscope—procedures that have changed little in the past hundred years. Yet the procedures are effective: one can often ascertain the cause of death by simple observation, and more sophisticated techniques are rarely needed. If a portion of the patient's heart is pale yellow (not the red-brown of normal cardiac tissue), the diagnosis does not require elaborate analysis: the patient had a heart attack. Most congenital heart abnormalities are also obvious on inspection.

When sophisticated postmortem analysis is necessary, pathologists have at their disposal an array of diagnostic techniques that rivals those in any branch of medicine for sensitivity and specificity. Electron microscopes that magnify to several million times enable pathologists to distinguish between viruses, to detect abnormal cell structures, and, coupled with X rays, to identify chemical elements in tissues—to determine, for example, the specific type of asbestos lodged in a lung. Microscopic specimens are today measured more precisely and analyzed more efficiently with computerized instruments, which can determine, say, the relative volume occupied by various cell components in a specimen to detect the high nucleus-to-cytoplasm ratio characteristic of many malignant cancers. Immunocytochemistry—the use of antibodies to "tag" a hormone or an enzyme—provides a test for the by-prod-

ucts characteristic of various diseased cells. And in situ hybridization—in which chemically labeled DNA is used to locate matching strands of DNA or RNA in tissue samples—is proving a powerful tool for detecting abnormal proteins and hormones in tissues; it has recently been used to locate DNA from the virus HTLV-III in the lymph nodes of AIDS patients, thus helping implicate this virus in the disease. In short, contrary to the contentions of some clinicians, the autopsy is not outmoded.

Physicians also complain that autopsies are done by inexperienced staff, and on this count the critics are often correct. Performing an autopsy can be intellectually rewarding, but it is a twenty-hour procedure that commands a fee of only two hundred to four hundred dollars. Thus, at many medical centers, postmortems are performed by first-year residents or nonphysician pathology assistants. It is ironic, then, that autopsies, though not lucrative enough to attract senior medical staff, are criticized as being too costly. Because insurers do not reimburse for autopsies (and thus patient's families usually are not charged), and because the government and private organizations that support health care prefer to fund clinical research rather than research programs related to autopsy, hospitals end up paying the entire cost of postmortem examinations—a cost that, including personnel, supplies, and facility maintenance, can run as high as two thousand dollars a case. Still, considering the pedagogical value of the autopsy, and the fact that medical bills for, say, patients with chronic illnesses or who require intensive care often exceed several hundred thousand dollars, the autopsy remains one of the few medical bargains left.

WHAT IS the autopsy's value? Most obviously, it brings to light errors in diagnosis and shortcomings in treatment, which helps physicians improve their clinical judgment. But there are other uses as well. Autopsies can provide information about the side effects of new drugs. The Armed Forces Institute of Pathology, in Washington, D.C., drawing information from autopsies performed around the country, keeps a register of adverse reactions to drugs—a potentially invaluable resource to the physician whose patient is suffering one of the earliest reported reactions to a new medication. Autopsies of children frequently uncover disorders that form the basis for genetics counseling and thus contribute to healthier future offspring. When a seven-month-old infant died at the Washington University Medical Center, for instance, autopsy revealed atrophy and other changes in the pancreas that were characteristic of cystic fibrosis. The parents, who had other, healthy children, were unaware they carried genes for the disease, and had been planning another pregnancy. The autopsy findings allowed informed family planning.

On a broader scale, autopsies are an enormous source of untapped epidemiological data. At present, such use of autopsy information is limited because most pathology services keep their postmortem reports on paper, requiring tedious manual searching to retrieve demographic or diagnostic data. Computerization of autopsy records, however, has begun. The pathologist John Carter, of the Case Western Reserve Medical Center, in Cleveland, has directed a pilot study to create a national autopsy data bank accessible from medical centers across the United States. From this data bank, information on cases of infectious disease could be sent to the Centers for Disease Control, in Atlanta, to aid in the identification of epidemics. Computerized autopsy data could also be fed to the National Center for Health Statistics, in Hyattsville, Maryland, to corroborate nationwide statistics on the incidence of different diseases and causes of death. These morbidity and mortality data, which are widely used health statistics, are currently derived from death certificates—even though studies have found that diagnoses listed on death certificates (generally filled out by whichever physician happens to be present at the patient's death) are wrong in fully half of all autopsied cases. Finally, insurance companies and government agencies that fund health care could use computerized autopsy data to measure the quality of the treatments they support.

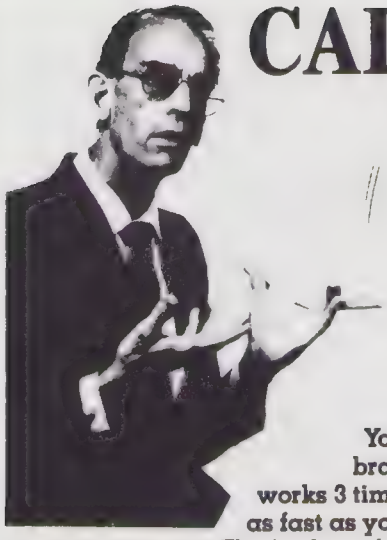
Eventually, autopsy data banks may prove a powerful tool for clinical research as well. At the Washington University Medical Center, the pathology department and a local computer company are developing a data bank that will include, for each of more than thirty-four thousand autopsies performed at the hospital, not only a full autopsy report, with digitized versions of photographs taken during the postmortem of diseased organs, lesions, and microscopic tissue specimens, but also the patient's demographic information, medical history, clinical diagnosis, and laboratory test results, as well as bibliographic references to reports of similar pathology in other patients. When such data are instantly retrievable in any combination, we will be able to answer questions about, say, the association of a particular cancer with age, sex, or race or its appearance in asbestos workers compared with its incidence in the population at large.

Admittedly, many physicians are skeptical about the validity of such findings; they argue, correctly, that to study only autopsied cases is to look at a biased sample. Still, even if autopsy studies cannot offer the final word on the epidemiology of a disease, they may provide the first clue that a new disease is on the rise or that a cancer is associated with a particular environmental condition or demographic variable. Unusual clusters of disease—the strange appearance, for example, of Kaposi's sarcoma and other telltale infections in young men, which was the first major sign of the AIDS epidemic—may be noticed only slowly through anecdotal reports in the medical literature but could be identified readily through computer analysis of nationwide autopsy data. If hospitals around the world were to participate in such networks, contributing data from millions of cases, the possibilities for establishing new patterns of disease would be immense.

That day may be coming. But first, physicians must be convinced that autopsy is neither a medical anachronism nor a legal threat. Postmortem examinations do expose misdiagnoses—mistakes that generally can be traced not to substandard work by the doctor but to the limits of medical knowledge. A revival of autopsies could stretch those limits if physicians, despite the onslaught of lawsuits, could drop the protective myth of diagnostic infallibility and admit that errors do occur. ●

DANIEL W. MCKEEL, JR., is an associate professor of pathology at the Washington University School of Medicine, and the director of autopsy pathology at Barnes Hospital and Children's Hospital, in Saint Louis.

CALCULATOR MATH?



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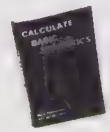

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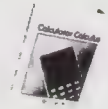

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STILLED LIVES

A Photographic Essay on the Specimens of Science

by ROSAMOND WOLFF PURCELL,
with text by EDWIN DOBB

SOMEWHERE in the scrublands of Costa Rica, a stunned bird—its talons withered and withdrawn; its eyes rolled back, revealing white—lay between the jaws of a bushmaster pit viper. Within minutes, the snake had its way with the fledgling, swallowing whole the down-coated meal. But before it could slither off to slumber and digest, the bushmaster, too, met its end—at the hands of a specimen collector. Indeed, so quickly did one death follow the other that when the viper's stomach was opened, the bird was still intact. Thus disentangled, bird and bushmaster were shipped to Harvard's Museum of Comparative Zoology, where they were placed, preserved in a bottle of alcohol, on a storage shelf in the department of herpetology. And it was there, years later, that Rosamond Purcell transformed the remains of a scientific postmortem into a provocative photograph.

Neither the bushmaster nor the other subjects of Purcell's pictures were meant for public display. They are specimens. And apart from arranging them in arresting compositions, as she has the flamingos on the cover of this magazine, Purcell has done little that would camouflage this fact. If she pulled both bushmaster and bird into the neck of their bottle before photographing them, her intent was not to convincingly re-

Bushmaster pit viper, *Lachesis muta*

construct a primal encounter between predator and prey but merely to create a suggestive pose. (Most revealing, the viper's venom-laden fangs are missing, a conspicuous absence that casts the implied violence of the scene into an ironic light. And, as anyone familiar with the species would recognize, the scales, normally the color of dead leaves, have been stained cobalt blue.)

Even more striking transformations are reflected elsewhere in this collection of creatures. But whether the change has been caused by scientists (an owl undressed to bone) or by natural forces (the heads of jungle fowl reworked by rot), one of the chief distinctions of these pictures is that they portray animals that have been *put to use*—that have been killed and, in one sense or another, digested by man: dismantled, probed, mounted, preserved, measured, catalogued. Concerned so with the ruins of an intimate relation between animal and man, a relation that is central to the scientific inquiry into living things, this portfolio of photographs is itself a kind of scientific endeavor—an archaeological investigation of natural history museums as conducted by a visual artist. In these scales and shells, feathers and bones, can be discerned the anatomy of a cardinal human appetite—the hunger to know, to lay bare, to see within.

What, of course, most often retreats before this appetite is life itself. There are no living things on these pages, no more than there are in museums. And yet, the footfall of the mastodon and the flight of the quetzal are never far away. Looking at a clutch of ibis eggs animated by sunlight, we are left wondering about what might have emerged. Staring at the bloated face of a toad, we recall a harsh throaty voice heard elsewhere. By rendering, in vigorous images, animals already made over by dissection or decay, Purcell commemorates the creatures' fugitive lives.

What photograph could be more emblematic of this theme of recurring transfiguration than the one depicting *Chamaeleo dilepis*, a creature with the curious ability to alter the color of its skin as it moves from one context to another? Seen floating in its shallow bath of glycerin, the chameleon has been treated with clearing chemicals to make its flesh transparent and with the red dye alizarin to highlight its skeleton. After a lifetime of shifting appearance, and having been resurrected as an object of human inquiry—stained with madder to instruct, and, one guesses, to delight, scientists—it is here transmuted into a totem for this entire family of images.

ROSAMOND WOLFF PURCELL's work has been exhibited throughout the United States and Europe and is part of the permanent collections of the Museum of Fine Arts, in Boston, the Victoria and Albert Museum, in London, and other museums. She has published two books of photographs: A MATTER OF TIME *and* HALF-LIFE. *The photographs on these pages, made at Harvard University's Museum of Comparative Zoology, will be shown this fall at the Marcuse Pfeifer Gallery, in New York City. EDWIN DOBB is a senior editor of* THE SCIENCES.

African flap-necked chameleon, *Chamaeleo dilepis*

Salvaged from a garbage dump, a copy of Ralph Ellison's book *The Invisible Man* acts as backdrop for an apparatus of bones. Scraps of words, the story's indecipherable debris, can be seen where the book jacket has been burned through and worn. The skeleton, too, is a barely legible fragment, of *Otus asio,* the common screech owl.

Four eggs of the glossy ibis, *Plegadis falcinellus,* nestle in a box on a museum shelf rather than on a platform of sticks in a marsh. The dark diagonal bands, reminiscent of brush strokes in a Japanese painting, are the tracks of Purcell's fingertips in the dust that coated the container's glass lid.

About the violence in his films, the French director Jean-Luc Godard once said, "But it's not blood, it's red." In the same spirit, the seemingly well-placed crimson color in this fossil *Dimetrodon,* or sail-backed reptile, is not blood but a patch of packing cloth. Purcell chose the specimen because it represents a complete transformation; what was once flesh is now stone.

Viewed at close range against a storm cloud of cotton, a single tooth of the American mastodon, *Mammut americanum,* might just as well be the entire lower jaw of a carnivore (the mastodon ate leaves). The tooth, usually between four and eight inches long, is crowned with cusps that wore down during the course of the mastodon's life.

To create this composition, Purcell drew upon a palette of feathers from the resplendent quetzal, *Pharomachrus mocinno,* of Mexico and Central America. Unlike the coloration found in most living things, which comes from chemical pigments that break down after death, the quetzal's brilliant green is the result of iridescence—light is split into different colors by the prismatic structure of cells in the bird's feathers—and so it endures indefinitely.

This still life of red jungle fowl, *Gallus gallus,* is a haunting meditation on how in death the singularity of bodies is magnified. Each head has been eroded by air and bacteria into a different shape and texture. When these birds had eyes —among the first organs to decompose—they gazed upon an Indian landscape.

Illuminated from behind, the glowing shell of a chicken turtle, *Deirochelys reticularia*, suggests the hull and cross-ribs of an ark. More than a coat of armor that the turtle hides within, the shell is actually an extension of the reptile's skeleton; the exterior plate is of a piece with the backbone and ribs.

In this photograph, we come face to face with the giant toad, *Bufo marinas*, solitary citizen of an alcohol sea—mute, motionless, contemplative; its eyes unyielding, its body gorged by osmosis. Staring at this buddha in a jar, we learn less about amphibians than we do about anthropomorphism.

Five underwing moths, *Catocala*, pinned to a book, seem either to hover high above a field or to lie embedded in a matrix of rock the color of charcoal and rust. The webbing of the book's spine is exposed where the cover has been flayed by rain and gutted by insects.

What appears to be a cluttered museum drawer is instead one of Purcell's own constructions—a fitting image with which to close this essay. As a cabinet of curiosities divided into compartments, the box is itself a museum, in miniature, of the old-fashioned sort—its arrangement guided more by chance and imagination than by taxonomic rigor.

BOLTS FROM THE BLUE

A New Theory of How Clouds Produce Lightning

by PETER H. HANDEL

John Constable, Cloud Study, *1821*

IN THE SPRING OF 1833, an unknown English naturalist knelt in the bare dunes along the Uruguayan bank of the River Plate, near Maldonado, and plunged his fingers into the sand. When he had dug as deep as his arms could reach, he carefully dislodged a two-foot-long tube of glassy stone that he would later say resembled "a shrivelled vegetable stalk, or the bark of the elm or cork tree." Matching fragments scattered on the dune's surface suggested that the tube had been at least five feet long. Three other cylinders, also broken, were buried nearby, one of them forked into rootlike shoots.

The young man on hands and knees was Charles Darwin. Sixteen months into the nearly five-year voyage of the *Beagle,* he had paused during a shore survey of South American wildlife to quarry for fulgurites—sand that has been fused by lightning into slender limbs. Finding in the bark of trees an analogy for the appearance of the tubes, Darwin inadvertently foreshadowed what only later, more rigorous forms of observation would reveal: fulgurites are the roots—or, more precisely, the records of roots—of a towering tree of light that bursts from the earth's surface, stretches into the clouds, and dissipates, all, apparently, within one instantaneous, blinding flash. Indeed, so swift is the light's passage that it seems to originate in the sky and shoot downward, like the fabled bolts hurled by Jupiter. But time-lapse photography has shown that what appears to be a single flash actually consists of several ascending and descending strokes and that, further, the luminous stroke—the event we recognize as lightning—actually begins at ground level and climbs into thunderclouds overhead, where it terminates in a canopy of tapering branches.

Darwin, a student of geology, was well acquainted with recorded accounts of fulgurites (the electrical nature of lightning had been established by Benjamin Franklin almost a hundred years earlier) and, after his discovery in the dunes, concluded that lightning tends to strike near the mouths of rivers—his contribution to what was then a small body of knowledge regarding the electrical activity of thunderstorms. That body of knowledge has grown considerably since the 1830s, but its outlines are still easy to sketch: When temperatures fall and winds mount within a high-vaulted cumulonimbus cloud, the thunderhead becomes positively charged at its top and negatively charged at its base. As the cloud migrates, its negatively charged bottom attracts a trailing shadow of positive charges in the ground below. Because air is an insulator, a poor conductor of electricity, the difference in charge between cloud and ground must build to a high level—to one hundred million volts in some cases—before resistance is overcome and a negative current flows freely from the region of excess positive charge to the region of inordinate negative charge (or, rarely, vice versa), equalizing the electrical difference between the two. If the discharge is sudden, a streak of lightning appears.

Every day, thousands of thunderstorms plow across the surface of the planet, generating an electrical current that winds up and down between the land and upper air layers. This current begins its passage through the troposphere,

the meteorologically active layer that occupies the first five to eleven miles of the atmosphere, in the form of lightning exchanges between Earth and thunderclouds. Exiting from the tops of these clouds, the current travels through the virtually weatherless zone called the stratosphere to an altitude of approximately thirty miles, where it enters the highly conductive ionosphere. From there it circulates around the globe, returning to Earth through regions of the troposphere that are free of storms (air, a leaky insulator, allows a very weak current to trickle through) and creating the fair-weather electrical field, a vertical separation of charge that exists throughout the lower atmosphere.

Rarely challenged and little revised since it was first proposed in 1916 by the Scottish physicist C. T. R. Wilson, this description of the global circuit is incomplete; it fails to address the most fundamental issue in the generation of an atmospheric current: How does a thundercloud become electrified? How do charges separate in a storm? And why in just the manner that they do—positive to the top and negative to the bottom? Until now, theories that claimed to solve the classic riddle of charge separation—and thus to reveal the origin of lightning—have been only partially informed about the electrical behavior of water. Discovered just during the past twenty years, certain consequential properties that microscopic ice crystallites and water droplets exhibit at temperatures near and below freezing permit the construction of a new model of cloud electrification—one that explains not only such familiar yet fearsome events as cloud-to-ground limbs of brilliant light but also virtually all other electrical phenomena produced in a thunderstorm.

ANVILS AND ANGEL'S HAIR, scudding ships and mackerel backs, mother-of-pearl rolled out in sheets: the many shapes that clouds assume give few clues to their composition. Each drop and every shard of frozen water in them is little more than the multiplication of a simple formula: two hydrogen atoms coupled with a single atom of oxygen. The glue that binds together this three-sided molecule is the electron.

Electrons, whose outermost orbits mark the boundary of an atom, bear negative charges, whereas protons, contained in the atom's nucleus, are positively charged. In a naturally occurring chemical element, the number of electrons equals the number of protons, and the atom therefore carries no net charge. Oxygen, with eight electrons and eight protons, is electrically neutral—as is hydrogen, its solitary electron balancing its single-proton nucleus. But some arrangements of electrons are less stable than others, and the atoms that possess these arrangements tend to acquire or lose electrons to achieve stability, becoming in the process either negatively or positively charged. Atoms so altered are called ions and the bonds they produce ionic.

Also seeking stability, some atoms form covalent bonds; they share electrons among themselves rather than lend electrons to their neighbors. Water is a covalently bonded molecule, and one that is asymmetrical: the two hydrogen atoms bend toward each other on one side of the oxygen atom, a configuration that leaves the water molecule polarized, its hydrogen end carrying a slightly positive charge and its oxygen end bearing a slightly negative charge. This manifest polarity is the key to its behavior: the region of negative charge attracts the hydrogen nuclei of adjacent water molecules, which are, in turn, bound in the same polar fashion to still other molecules, and so on, unto puddles, lakes, and seas. Hydrogen bonds remain random and relatively weak; breaking and reattaching without rest, they are responsible for water's viscosity, its fluidity—until the temperature drops below freezing, at which point the molecular assemblages become highly ordered, solid lattices of hexagonal rings: ice. Both water and ice come into play in a thunderstorm.

Storms are most common in the afternoon and early evening, when the sun has baked the ground enough to drive warm, moist air upward. If continually fed by fresh supplies of humid air, these updrafts accelerate and climb beyond the elevation at which water vapor condenses into water droplets (the exact altitude varies according to temperature and pressure), and the characteristic bulges of a

cumulus cloud take shape. Rising wind currents, attaining speeds of one hundred miles an hour, continue to raise the cloud's ceiling, pushing it far above the freezing level (which, during summer, is about two miles), where ice forms around bits of atmospheric dust. These microscopic crystallites, only one hundred to ten thousand angstroms in diameter (there are about two hundred and fifty *million* angstroms to an inch), grow rapidly by acquiring additional moisture and sticking to one another. Within the towering stack—now a full-blown cumulonimbus cloud whose anvil-shaped head may stretch as high as the upper limit of the troposphere, eleven miles into the sky—the weight of ice and water becomes too heavy for the updrafts to support. Precipitation begins to fall, creating downdrafts that, in turn, draw into the cloud cool dry air from the surrounding region. The descending currents grow more violent while, alongside, within the same cloud, fresh updrafts continue to surge. Then the brooding mass unwraps its rage—letting loose lacerating winds, cloudbursts, and ragged gashes of light.

SQUALLS AND DOWNPOURS are not surprising; the cloud merely gives back what it has taken. But how does this transient concoction of hydrogen and oxygen also manufacture electricity? The most common answers turn upon the two most obvious kinds of animation in a thundercloud: falling precipitation and convective air currents.

All versions of the precipitation model are based on ideas introduced in the late 1880s. By that time, it was known that the frozen droplets in a thundercloud stood a good chance of being polarized by the fair-weather field that surrounds the planet. Since, like the poles of a magnet, the dissimilar ends of electric fields are mutually attractive, a droplet's charge alignment will be the reverse of the charge distribution that yields the fair-weather field. (Recall that this field returns positive charge to the ground; the cloud-free troposphere can therefore be viewed as a weak but important segment of the global circuit that at high altitudes is positively charged and at low altitudes is negatively charged. The small charge separations, or polarizations, within this field—such as those that occur in a hailstone or an ice crystal—will be oppositely aligned.)

When a descending hailstone collides with a much smaller and slower-moving crystallite of ice, the positive charge on the bottom of the hailstone draws away some of the negative charge on the top of the crystallite. The crystallite, now carrying a net positive charge, is lifted by updrafts to the top of the thunderhead while the heavier and negatively charged hail cascades to the cloud's base. To be sure, the effect of a single collision is negligible, but millions upon millions of such collisions account, according to the precipitation model, for a thundercloud's overall polarization, the buildup of positive charge in the ground directly below the cloud, and the resultant climactic discharges both within the cloud and between cloud and ground via lightning.

The thermoelectric properties of ice (under certain conditions, heat can be transformed into electricity and vice versa through the thermoelectric effect) gave rise to an alternate precipitation model. This view has it that as cloud droplets freeze onto falling hailstones, they free la-

Gary Ladd, Kitt Peak, Arizona, *1972*

tent heat. When, later, the slightly warmer hailstones collide with ice crystallites, this heat is converted into electrical energy: the falling hail picks up a few loose electrons (and, thus, a negative charge) from the ascending splinters of ice. The ice, holding a positive bias, journeys to the top of the thunderhead, whereas the hail falls to the base, and the charges remain separated until discharged by lightning.

Although few meteorologists would quarrel with the plausibility of precipitation models, laboratory experiments have failed to substantiate any of their proposed collision mechanisms. But what makes these models especially suspect is their inability to account for the lightning strokes that occur at low levels of precipitation, or even before it forms, and—utterly inexplicable in these terms—for the polarization of clouds that never produce a drop of rain.

The convection model contends that charge separation is the result of thermally driven air currents that churn a cloud from top to bottom. These currents, the model suggests, transport the electrified particles either to the roof or to the base of the cloud, depending on their charge. What little is known about a cloud's convective mechanisms, however, gives scant support for this point of view. For one thing, the electrified region at the bottom of a thunderhead rarely exceeds twenty percent of the cloud's height and, in fact, usually occupies an even narrower layer, whereas convection would distribute negative charges throughout the cloud's entire lower half. What's more, neither the required concentrations of charged particles nor sufficiently vigorous air currents exist to explain the doubling of voltage that occurs every two minutes or less in a mature thundercloud. Further, studies of charge development have shown that lightning occurs as the climax of a thunderstorm—the violent opening note to what in fact is a quiescent finale, a period when the winds, convective or otherwise, are dying down. Finally, the most intense lightning discharges have been measured in shallow winter snowstorms that occur over Japan, storms in which horizontal currents are common but updrafts rare —in which convection hardly exists.

Something is amiss when the two leading theories of cloud electrification fail to explain so many of the phenomena they are intended to illuminate. The shortcomings are understandable, however, since neither model takes into account the full range of electrical phenomena exhibited by ice.

DEPENDING ON which of its properties one wants to emphasize, ice can be considered a poor insulator or a weak conductor; either way, it partially resists the flow of an electrical current. Electrons cannot drift freely about in an insulating substance—or, at least, not nearly to the degree that they can in a good conductor. When a negatively charged wire (one that carries an excess number of electrons) is brought toward a copper bar, extra electrons jump from wire to conductor, where they pass rapidly from atom to atom, like runners in a relay race. But when the same wire is placed near an insulator—glass, for instance—the electrons in the glass merely shift slightly away from the wire while causing the glass's atomic nuclei, with their positive protons, to move slightly toward it.

John Constable, Study of Cumulus Clouds, *1822*

Unlike the river of electrons that flows through a conducting material, the charge that builds up in an insulator is immobile; it is bound to fixed positions. For this reason, insulators exposed to an external electric field tend to become polarized—to develop and hold fields of their own. Most important for an understanding of the electrical properties of ice is that, in certain crystals, mostly salts, polarization can be induced simply by lowering the temperature below certain well-defined thresholds. Above these temperatures, heat agitates the atomic bonds of these unusual compounds, called ferroelectrics, kindling varying degrees of randomness and disorder that cannot be overcome by the forces that would otherwise induce polarization.

In 1968, H. Peter Glockmann, of the Technical University of Munich, reported that he had witnessed extremely small spontaneous polarization effects as he cooled down samples of ice—a surprising discovery, since the ferroelectric transition point for bulk ice had been estimated to be about minus two hundred and fifty degrees Fahrenheit, a temperature reached nowhere on the planet. Shortly afterward, these electrical effects were mathematically confirmed by a number of theoreticians. Yet, even today, the full implications of Glockmann's discovery have not been explored.

The ideal ice crystal, exemplified in such exquisite structures as snow crystals, can be pictured as a rigid lattice of uniform hexagons held together by hydrogen bonds. Microscopic cloud crystallites are rarely so rigorously ordered; far more common is the lumpy aggregate or the shard that has accreted haphazardly to a bit of sand or to an errant chemical. Irregularity is the rule—a decisive turn of events, since it is the flaws that lend to ice its most important electrical properties. Within these flawed regions, hydrogen bonds are distorted and weakened in various ways. Equally important, these bonds are not surrounded on all sides by layer after layer of similarly static chemical grids. Thus, the hydrogen atoms that border defects are free to reorient themselves, which is what they do when the temperature reaches the unexpectedly high ferroelectric transition point for crystallites. Behaving as if they belong to isolated molecules, the hydrogen and oxygen atoms follow their natural inclination to become polarized.

It is likely, therefore, that ferroelectric polarization occurs the moment water droplets begin to condense and freeze into crystallites, when they are only one hundred to one thousand angstroms in diameter, and persists as the particles accumulate more moisture—perhaps until they grow to about ten microns (one inch equals about twenty-five thousand microns). Above this size, the aggregates of water molecules become too rigidly ordered—like the ice crystals found in common bulk ice—to allow charges to separate. Though insignificant in themselves, such individual polarizations in tandem with millions of others could produce all the electrical phenomena we associate with thunderstorms.

WITHIN EACH OF THE ICE CRYSTALLITES that compose the upper two-thirds of a mature cumulonimbus cloud, positive and negative charges thus appear spontaneously at the ends. Each electrified crystallite influences its neighbors, causing them to align their plus and minus ends tentatively in the same directions. When the concentration of polarized ice reaches a sufficient level, an avalanche of electrical reorientation occurs, pulling all of the remaining unpolarized crystallites into alignment. This collective runaway effect resembles what is known in molecular physics as a polarization catastrophe.

For several hours, the catastrophe continues to spread, and, in time, the entire cloud becomes polarized, with an overall positively charged bottom and negatively charged top. The strength of this field is such that the bound charges draw ions of opposite charge into the cloud; positive ions, both in surrounding air masses and from within the cloud itself, are attracted to the top, whereas negative ions are attracted to the bottom. The combined effect of these free charges is to make the cloud appear electrically neutral; they mask the overall charge separation caused by the polarization catastrophe.

When, finally, the ice crystallites begin to adhere to one another and thereby exceed the size at which they can hold a field, the polarization catastrophe abruptly ceases. Ice assumes its normal electrical state (it loses its polarity), and the bonds that fixed the free positive and negative ions at the cloud's extremes are destroyed. No channels exist that might quickly drain off the massive charges in these collections of ions. Abruptly liberated, they discharge violently: lightning strikes the nearest object bearing an opposite charge, be it the ground, another cloud, or the atmosphere itself, and with such searing intensity that it literally detonates the air along the jagged channels it cuts into the sky. Anyone who has heard a thunderclap at close range can attest to the ferocity of such charges unbound.

But a single episode of lightning does not a storm make. As long as warm, moisture-laden air is driven upward, the thundercloud will freight forward, refueled with polarized ice crystals, disgorging rain and heaving hot, white bolts this way and that. In violent thunderstorms and tornadoes, the buildup and breakdown of polarization may occur so rapidly that lightning is virtually continuous. Only when the updrafts die do the clouds dissolve. Water trickles into the soil, slaking the thirst of plants and cooling the backs and bellies of animals. A fresh stream of electricity feeds the fair-weather field. And those whose dread and fascination have made of storms a thing of awe may walk beneath azure skies—perhaps, like Darwin, to come upon a remnant of the cataclysm rooted in sand. ●

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NIGHT NOISE

The Puzzling Link Between Snoring and Disease

by PETER G. NORTON AND EARL V. DUNN

Thou dost snore distinctly,
There's meaning in thy snores.
—William Shakespeare, *The Tempest*

IT IS THE WHITE NOISE of army barracks and college dormitories, a nocturnal chorus issuing from millions of bedrooms. The Irish dramatist George Farquhar, in his eighteenth-century comedy *The Beaux' Stratagem,* called it "the tuneful serenade of that wakeful nightingale—the nose." Not everyone, however, has been so charmed. Firemen have lost their jobs because of snoring, and marriages have been ruined. The wife of Melvin Switzer is now deaf in one ear and sleeps with her good ear to the pillow. Mighty Melvin, a two-hundred-and-fifty-pound dockworker, has blasted his way into history, or at least the *Guiness Book of World Records,* with a snore of eighty-eight decibels—about the same intensity as a motorcycle engine being revved at full throttle. According to the British magazine *New Scientist,* the nineteenth-century American outlaw John Wesley Hardin once found the stertorous outbursts of a fellow hotel guest so offensive that he burst into the sleeper's room and silenced him with a gun.

Clearly, snoring can be an acoustical annoyance, but, out of range of gunfighters, does it pose any real risks? If conventional medical wisdom holds that snoring is innocuous for the great majority of people, recent evidence suggests otherwise. Three studies, involving more than fifteen thousand people in North America and Europe, have produced nearly identical findings: snorers are more than twice as likely as nonsnorers to have high blood pressure, even when matched for age, sex, weight, smoking habits, and other factors. Snoring is also associated with a host of other ailments ranging from heart and lung diseases to allergies and asthma. Indeed, snoring divides the population into two groups, one more likely to be sick than the other. Though we can only surmise the reasons for this link, it raises an intriguing question: Might treatments for snoring also improve health?

ALTHOUGH PHYSICIANS have speculated for at least one hundred and fifty years about the reasons for snoring, its cause remains elusive. In 1841, the German physician B. E. Hoppe proposed that snoring was a necessary respiratory function for clearing mucus from the throat. More imaginative, perhaps, but no more accurate was the theory advanced by a later psychologist, who claimed that men snore out of an unconscious desire to punish their wives. Women themselves have responded with a more flattering interpretation; according to Marie Stopes, the author of the 1956 book *Sleep,* some ladies believe that their snoring husbands are reliving primitive days when men made noises to frighten away vicious beasts.

The otolaryngologist Marcus Boulware, in the 1974 text *Snoring,* listed six postulated causes of snoring, ranging from anatomical abnormalities, such as enlarged adenoids and buckteeth, to the vibration of parts of the throat and mouth, including the tongue and soft palate. Vibration theories probably come closest to the truth. The pharynx —the airway that leads from the mouth to the esophagus, and branches off, en route, to the larynx, or voice box—contains muscles that, with the muscles of the soft palate, must stay taut to keep the throat open. When these muscles slacken during sleep, the soft palate may fall toward the rear wall of the pharynx, particularly if the sleeper is on his back. As the sleeper breathes, the rush of air apparently causes parts of the slackened palate and pharynx to vibrate, producing a snore. Thus, the British otolaryngologist Peter E. Robin has defined snoring as sounds made by various kinds of vibrations of the soft palate and the posterior faucial pillars (muscle-covering membranes that lead from the mouth to the pharynx).

In a small fraction of snorers, relaxation of the throat muscles completely closes the pharynx, and the sleeper stops breathing for ten seconds or more, until choking rouses him. Then his muscles tense, his throat opens, and he resumes breathing. Soon, however, the sleeper's throat may close again, causing another episode of apnea, or temporary respiratory arrest. The process may be repeated dozens of times a night. The sufferer, roused so often during sleep, is then drowsy and tired all day. First described in 1965 by Henri Gastaut and his colleagues at the National Institute of Health and Medical Research, in Marseilles, sleep apnea syndrome has since been linked to fatigue, depression, low oxygen content of the blood, hypertension in the vessels that lead from the lungs to the heart, and, for unknown reasons, hypothyroidism and hy-

James Gillray, Fast Asleep, *1804*

perpituitarism. Sleep apnea is rare, however; it afflicts only about one percent of the population, often people with anatomical abnormalities in the throat. It is not a problem for the great majority of snorers.

The more mundane snorer, in fact, has attracted little medical attention. During the 1970s, only eight articles specifically addressing the topic appeared in the medical literature, most dealing with the frequency of snoring in the population. When large samples of people were asked if they snored, the habit was reported to be rare: only seven to forty percent admitted to snoring. Mark Twain, however, in *Tom Sawyer Abroad*, had something to say about this research methodology: "There ain't no way to find out why a snorer can't hear himself snore."

To get around this difficulty, a 1980 study asked two hundred and fifty-four Canadians whether anyone in their families snored. Eighty-six percent of wives reported their husbands to be snorers, and fifty-seven percent of husbands reported their wives. In all, it seemed, more than half the adult population of Canada snored. In the same year, a study of nearly six thousand residents of San Marino, a tiny country on the Italian peninsula, revealed that forty-one percent of men and twenty-eight percent of women were snorers, with the prevalence increasing through the seventh decade of life, when about sixty percent of males and forty percent of females habitually snored. Contrary to accepted medical knowledge—though not, perhaps, to everyday observation—snoring is common. If snoring is indeed hazardous, the risks are shared by millions.

In 1984, we asked more than two thousand people visiting their family physicians in Toronto which members of their households snored and how often. Our subjects were also asked to report whether each family member suffered from any of thirteen broad categories of illnesses, such as allergies and heart and lung diseases. The sample included men and women from diverse occupations and ethnic and socioeconomic backgrounds, and was widely distributed by age, there being more than two hundred people in each ten-year age group from thirty to ninety. The frequency with which subjects reported such diseases as hypertension, diabetes, heart disease, and obesity roughly matched the reported prevalence of these conditions in Canada and the United States. Our sample thus appeared representative of the populations of both countries.

Seventy-one percent of husbands and fifty-one percent of wives in our sample snored. Snoring occurred with equal frequency among people from each ethnic background and each level of family income. It was much more common, however, among the ailing—even those with

Honoré Daumier, Paris Streets Are Beginning to Look Like This Every Night, *1857*

nonrespiratory complaints. In this sample and, presumably, in the population at large, people who snored were more likely than nonsnorers to suffer from hypertension, heart and lung diseases, arthritis, obesity, insomnia, depression, diabetes, asthma, alcoholism, and excessive daytime drowsiness. The differences persisted when snorers and nonsnorers were matched for age, sex, and marital status. Moreover, with all but two of these medical conditions—insomnia and asthma—the more a person snored each night, the more likely he was to suffer the condition. The prevalence of snoring increased with age until people reached their seventies, then it declined—perhaps because, by their eighties, more snorers than nonsnorers had died from snoring-related diseases.

The greatest difference between snorers and nonsnorers was in their risk of hypertension and heart disease. Since obesity and smoking are more common among snorers than among nonsnorers, it seemed likely, at first, that the frequent cardiovascular problems suffered by snorers related more to their excess weight and smoking than to their nighttime stertors. But even male snorers who neither smoked nor overate were found to have a 2.2 higher risk of hypertension and a 1.2 greater risk of heart disease than that of nonsnorers. Among women, snoring seemed to raise the risk of cardiovascular disease even more than among men. (This apparent sex difference may, however, be an artifact of our data-gathering methods. If men are less disturbed by nighttime noises than are women, as studies of people living near airports indicate, then women reported by their husbands to be mild snorers may actually snore as loudly as men considered severely stertorous by their wives.)

Two other studies of snoring—the one in San Marino, conducted by Elio Lugaresi, of the University of Bologna, and a 1985 study of more than seven thousand Finns, led by Markku Koskenvuo, of the University of Helsinki—have examined the risks of hypertension and heart disease among snorers. Both studies reported differences in risk between snorers and nonsnorers almost identical to those found in our Canadian study. And another Finnish research team, headed by Markku Partinen, of the University of Helsinki, recently found, after statistically canceling the effects of age and obesity, that snorers had a 2.8 greater risk of suffering strokes. The connection between snoring and cardiovascular conditions, then, not only seems real but appears to hold across cultures as well.

Why is snoring associated with disease? We can only guess. Alcohol and certain tranquilizers, which are known to relax the pharyngeal muscles, increase the frequency and loudness of snoring; perhaps disease similarly impairs muscle tone and thus leads to snoring. Alternatively, snoring may cause disease. It is known that in people who have chronic bronchitis—whose airways are clogged with mucus—the blood vessels in the lungs receive too little oxygen, and eventually, for reasons poorly understood, the vessel walls begin to thicken, causing pulmonary hypertension. Perhaps a similar mechanism is at work in people who snore. The snorer's partially obstructed airways may prevent a normal supply of oxygen from reaching the blood, triggering changes in the vasculature and resulting in high blood pressure. Such pulmonary hypertension may, in turn, predispose snorers to a range of other illnesses, including general hypertension, heart disease, and diabetes. This chain of causation is, of course, highly speculative. But if future research supports the notion that snoring is a cause of disease, treatment of the severe snorer may prove advisable.

LEGIONS OF REMEDIES for snoring have been proposed over the years, most of them dismal failures. During the 1920s, surgeons attempted injecting paraffin into the soft palate. In the fifties, physicians tried amputating the patient's uvula, the small fleshy lobe that hangs from the rear of the soft palate. Removal of the adenoids was, until recently, an accepted treatment, though it worked for only about ten percent of patients.

Since 1874, the U.S. Patent and Trademark Office has issued patents for more than three hundred antisnoring devices, including chin straps, shocks, and alarms to wake the nighttime offender when he begins to snore, and wooden pillows to keep him off his back—a position conducive to snoring. Many diehard snorers, though, manage to snore in any position, even sitting.

A few homespun remedies have proved effective. For the person who snores only when on his back, a tennis ball sewn into the back of his pajama top may be all that is needed. If snorers can stop smoking and lose weight, the frequency and loudness of their nocturnal outbursts might decrease dramatically. (The reason for the improvement is unclear. Perhaps throat tissue chronically irritated by smoke is more likely to vibrate; and obesity may change a person's breathing patterns as well as predispose him to sleeping on his back.)

For people whose snoring is a serious problem—who suffer sleep apnea or simply snore so loudly that their mates cannot tolerate the noise—several new surgical procedures to alter the anatomy of the pharynx may help. The most common is a five-year-old procedure, developed by the Detroit surgeon Shiro Fujita, in which a small tuck is taken in the soft palate and the pharynx to tighten the back of the throat. Called a palatopharyngoplasty (and nicknamed the pharyngeal face-lift), the operation is scarcely more serious than a tonsillectomy. It does not put a stop to snoring entirely, but encouraging results have been reported in French, British, and Canadian medical journals, with almost one hundred percent of patients enjoying dramatic reductions in snoring immediately after surgery and fifty-four percent snoring less after one year. In addition, nasal continuous positive airway pressure, a technique used to treat sleep apnea, by continuously pumping air through a nosemask into the sleeper's airway to keep his pharynx open, has also proved effective.

The next stage in snoring research will be to test the hypothesis that a reduction in snoring, surgically or by other means, will lead to a long-term decline in hypertension. Results from such research will begin to reveal whether the habit is indeed the cause of the many illnesses with which it is associated. If so, new techniques to reduce snoring may prove to be not only a restorative for beleaguered bedmates but also a drug-free way for millions to combat high blood pressure and reduce the risk of heart disease. ●

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Vasily Kandinsky, Dominant Violet, *1934*

PICTURE UNDER PRESSURE

An Artist Plumbs the Ocean Depths for Inspiration

by VIVIAN ENDICOTT BARNETT

VASILY KANDINSKY was sixty-seven years old when, late in 1933, he left his adopted country, Germany, and moved to France. By the time the Russian artist resumed work, in February of 1934, it was apparent that there was more to the journey from Berlin to Paris than a simple change of residence. Into his once totally abstract paintings, Kandinsky introduced motifs derived from the natural world—shapes that bear a subtle but decisive resemblance to amoebas, snakes, and sea creatures. Combining geometric forms with evocations of marine invertebrates, *Dominant Violet,* painted in June of 1934, exemplifies the way in which Kandinsky incorporated this new iconography into his abstract pictorial universe.

The painting depicts an underwater menagerie—a fanciful assortment of stylized sea creatures adrift among sharp-edged triangles and multicolored bars. The large, billowing forms at the upper left are reminiscent of the medusa, or jellyfish, and the dark shape at the lower right suggests the same animal in cross section. A red-and-pink nematode, or parasitic worm, bends gracefully across the right half of the picture. The undulating pink pattern at the upper right echoes the shape of a firola, or sea snail, and the whimsical whiplash lines and flagellate forms throughout the painting recall the curves and swaying motions of fish and seaweed. Kandinsky emphasized these marine allusions by adding shaded zones of sand to the canvas, making such elements as the large medusa at the top center stand out in low relief.

Kandinsky's interest in scientific and natural images predated their appearance in his work by at least ten years. In preparation for the book *Point and Line to Plane,* published in 1926, he had copied several illustrations from *Die Kultur der Gegenwart,* a German encyclopedia that belonged to the artist and still exists in the Kandinsky archive at the National Museum of Modern Art, in Paris. The markers and notations found among its pages, especially in the volume on zoology, strongly suggest that the artist used the encyclopedia as a source of images. Then, in the early thirties, when he was teaching at the Bauhaus, in Dessau, he saved numerous magazine and newspaper clippings that depicted a variety of marine animals in embryonic stages and microorganisms shown under high magnification.

For Kandinsky, all these creatures were more than straightforward sources of inspiration. Long before they found direct expression in his work, they served as a metaphor for the evolution of abstract art. In *Point and Line to Plane,* he referred to his paintings as art organisms, living entities whose stage of development was equivalent to that of amphibians, representing the beginning rather than the conclusion of a creative process. Arriving in Paris toward the end of his seventh decade, Kandinsky drew upon the world of biological imagery to start a new and, as it happened, final phase of his work. In *Dominant Violet,* with its unmistakable references to the waters of life, he evoked his own regeneration and the growth of his creations as well as many of evolution's most enchanting species. ●

VIVIAN ENDICOTT BARNETT, curator of the Solomon R. Guggenheim Museum, in New York City, wrote KANDINSKY AT THE GUGGENHEIM *and "Kandinsky and Science: The Introduction of Biological Images in the Paris Period" for the exhibition catalogue* KANDINSKY IN PARIS, 1934–1944.

'I AM BECOME QUITE A GAUCHO'

by HORACE FREELAND JUDSON

THE CORRESPONDENCE OF CHARLES DARWIN: Volume I, 1821–1836
Edited by Frederick Burkhardt and Sydney Smith
Cambridge University Press; 702 pages; $37.50

A CALENDAR OF THE CORRESPONDENCE OF CHARLES DARWIN, 1821–1882
Edited by Frederick Burkhardt and Sydney Smith
Garland Publishing, Inc.; 690 pages; $100.00

At the end of October of 1831, Charles Darwin, twenty-two years old, wrote a letter from Devonport, the Royal Navy's station and dockyards hard by Plymouth, to his sister Caroline, nine years his elder, at the family seat, in Shrewsbury, in the west of England, across the river Severn from Wales. Darwin had taken lodgings in Devonport while awaiting the final fitting out of the brig HMS *Beagle* for the expedition to survey the southern coasts of South America in which he was to act as naturalist, under the command of Robert FitzRoy. His letter was fussed with industry and gossip, asking his sister to help him clear up petty financial and social obligations; the excitement of his prospective adventure had well taken hold. "I shall begin very soon to stow away my things; but I do not suppose I shall sleep on board till about a week before starting," he wrote. He ended, "Love to Susan," another sister, "and tell her I will not take Persuasion, as the Captain says he will not read it, & there is no danger of my forgetting it. More letters the better. Love to all: hurra, for the Valparaiso Volcanoes."

Thus, in three sentences—joyful, yes, and emblematic even in that—Darwin prefigured his next five years. He was putting *Persuasion* and Jane Austen's ordered England behind, though unforgettably and with love, for the irruptive natural history of South America: letters would knit the two worlds together.

After a couple of starts beaten back by storms, two days past Christmas the *Beagle* at last left Plymouth. She was supposed to circumnavigate the globe in two years but did not make England again until October 2, 1836. Caroline, Susan, and the youngest sister, Catherine, took it in turns to write Darwin all the news. His elder brother, Erasmus; cousins and friends of his youth; and his Cambridge mentors in geology and natural history wrote, too. Darwin wrote back, vividly, enthusiastically, at length. They all committed correspondence to every ship of opportune destination they learned of. Letters crossed, overlapping one another by months. Despite fears Darwin frequently mentioned, few letters were lost, and yet at times he went without word from home for half a year. That the voyage was epic in itself and in its consequences we now almost take for granted. Yet its singularity is made fresh by the address those in England used for him most of that time. Nonchalantly he advised correspondents: "'H.M.S. Beagle, S. American Station' will find me."

Darwin left England obscure and untried. He had been nominated to the *Beagle* by his Cambridge teacher the botanist and mineralogist John Stevens Henslow, who wrote to him, with transparent candor:

> I have stated that I consider you to be the best qualified person I know of who is likely to undertake such a situation—I state this not on the supposition of y^r being a *finished* Naturalist, but as amply qualified for collecting, observing, & noting any thing worthy to be noted in Natural History. . . . Capt. F. . . . would not take any one however good a Naturalist who was not recommended to him likewise as a *gentleman*.

The post was unsalaried; in fact, Darwin had to pay all his expenses. He returned an accomplished field naturalist, with innumerable important discoveries in hand, and the next month was elected a fellow of the Geological Society. His letters from South America—particularly the running accounts of his observations that he sent to Henslow—had made him well known among scientists in England. A year before Darwin's return, Henslow had edited generous portions from ten of the letters into a pamphlet he read before the Cambridge Philosophical Society on November 16, 1835, and distributed to the society's members. Two days later, in London, a different, shorter selection from the letters to Henslow was read to the Geological Society by another of Darwin's mentors, the geologist Adam Sedgwick, and a report of this was published in the society's proceedings. These edited excerpts were Darwin's first scientific publications.

From the whole of Darwin's life, at least thirteen thousand nine hundred and fifty-five letters that he wrote or that were written to him survive; when the *Calendar* of his correspondence went to press, in midsummer 1984, the count stood at thirteen thousand nine hundred and five;

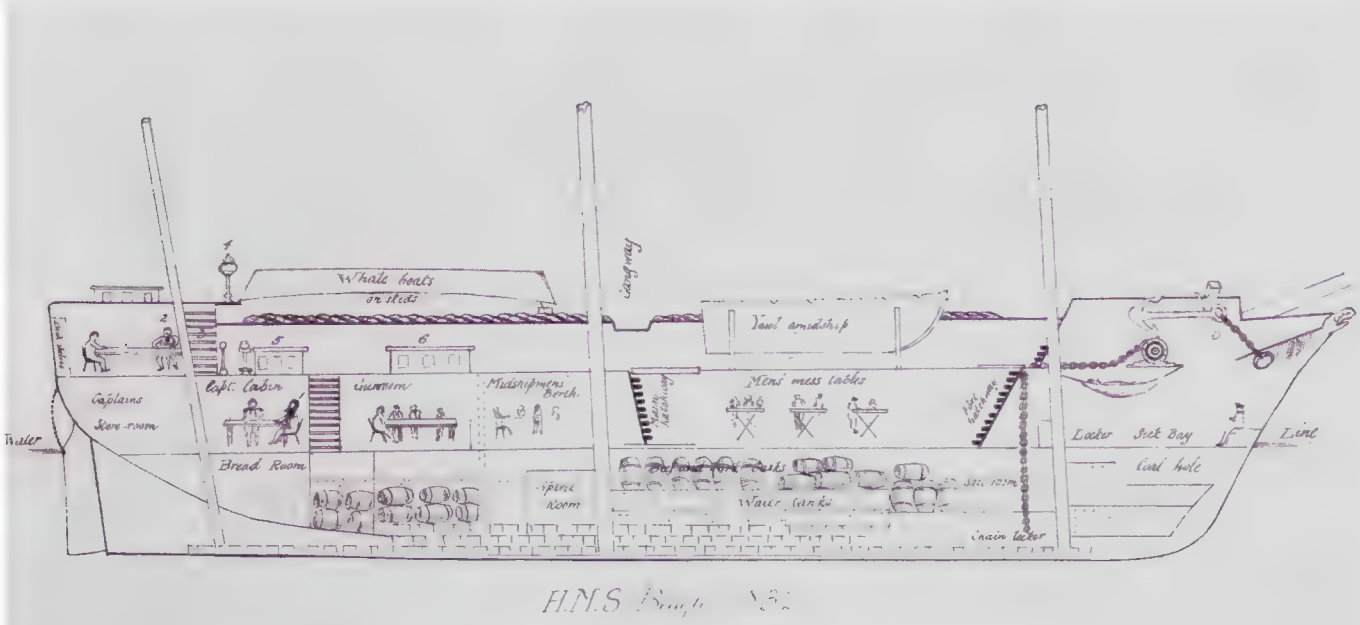
George Richmond, Charles Robert Darwin, *1840*

since then, about fifty more have turned up in archives and at auctions and in the catalogues of antiquarian dealers. The correspondence begins when he was a schoolboy, with letters from friends and family, chiefly Erasmus; the earliest three hundred and thirty-eight items take us up to December 30, 1836, and a cheerful note from FitzRoy, who had got engaged to be married almost as soon as he came ashore and was now snowed up in Bedfordshire. FitzRoy wanted to consult with Darwin about plans for publishing the journals of the expedition—which sounds a pleasing cadence to end the first volume of what is to be a complete edition of the correspondence.

The numbers prompt calculations. The first volume presents less than two and a half percent of all the letters. Frederick Burkhardt, joint chief of an editorial team that at present numbers ten, said recently that the edition will run to twenty-five volumes—"that is, if we don't decide we're forced to print just summaries of some of the least important letters *to* Darwin from the period after 1862, when he started saving *everything*." The enterprise will require another six volumes to reach the vicinity of *On the Origin of Species*, which appeared at the end of 1859. At a planned rate of one volume or sometimes two a year, the last letter known—about the evolutionary reason why dogs bury bones, which Darwin wrote on April 17, 1882—will not appear until well past the turn of the millennium. To be sure, scholars able to travel have had access to most of this corpus, and slim but important strands of the correspondence have been in print before. In 1887, five years after Darwin's death, his son Francis published a collection of the letters and followed with more in 1903. Half a dozen other significant small portions have come out since then. Most notably, Nora Barlow, a granddaughter, edited Darwin and Henslow's interchanges, taking them through the first publication of the *Origin* and its initial reception; Lady Barlow's book appeared in 1967, aptly titled *Darwin and Henslow: The Growth of an Idea*. Thus, the letters previously published are a highly selective fraction of the total and, for that very reason, unrepresentative.

The correspondence of Darwin or Faraday, of Freud or Einstein—or, for that matter, of Mozart or Henry James—bears a dual relationship to the historical figure. In one respect, the correspondence is distinctly secondary. It is not the man's work, which stands alone for judgment; nor is it a coherent account of the life, which, for such figures, interests us in the first place because of the work. We read the correspondence dependently, only in relation to the work and the biography. Yet in another sense the correspondence is prior. Obviously, it is indispensable raw data of the life. Further, a letter from the laboratory or the field or the study may catch the work in motion—the observation with the dew of surprise still on it, the idea struggling from its chrysalis. When such letters grow into an exchange lasting months or years—as for Darwin and Henslow—themes emerge, transform, adapt to comment, and gain muscle and subtlety in ways that illuminate the working of ideas as the eventually published paper or book cannot. More than all that, though, letters set the work in context, intellectually, professionally, socially. The importance of the context of scientific discovery grows with distance in time; as nothing else, a copious correspondence allows us to reconstruct—rather, *to grow into*—that context. Darwin himself explained this. Shortly after making landfall in Brazil, writing to his second cousin William Darwin Fox, an old, intimate friend, he said, "Remember minutiae become more not less interesting, as the distance increases."

The most important single consequence of Darwin's endeavors during the voyage of the *Beagle* was, of course, his conversion from the orthodox, unexamined conviction that species are individual, essentially unchanging creations to the belief that they arose by transmutation, across aeons, from previous forms. His acceptance of the



Philip Gidley King, Diagrammatic Section of the Beagle, *1890*

likelihood of transmutation did not take place aboard the *Beagle*, but probably during a period of days or weeks beginning in March of 1837, or about six months after his return (and three past the close of this volume). By that time, other naturalists had started to classify his collections systematically; their work and his own were bringing him to realize how the classifications were systematically unique—and what that entailed. To be sure, late in the notebooks, catalogues, and diary that he wrote during the voyage, he had started to connect observations that, if true, he wrote at the time, "would undermine the stability of Species." Yet he appears to have put away such doubts. In any case, the letters from the voyage carried no flicker of a suggestion of the transmutation of species—not those to Henslow and other naturalists and of course not those to family and friends. No, we must await later volumes of the correspondence or look to his later notebooks (these, too, have been published) for the first steps and subsequent turns in development of the theory of evolution by natural selection.

Yet as the letters crossed between England and the South American station, a conversion did take place, not without poignance. Ever more clearly, Darwin responded to a vocation, in the strong, primary sense in which his time understood that word: a calling to a special work in life. With that, his tone deepened, his confidence firmed—even as the contrast sharpened between what the world he had emerged from expected and what he was coming to be. The letters show his family, his old friends, his class and background, indeed all that Shrewsbury represented, in tension with Cambridge and London, the pursuit of new understanding, and the fellowship of the small British community of natural history. The tension was inevitable. But as Darwin's family and friends, and his intellectual mentors, came to recognize the change in him, the tension had to be resolved. The social beliefs and intellectual attitudes of Shrewsbury emerged, after all, as complex, benign, and meliorist: progress seemed attainable, step by step. These were ardent men and women, marked by generosity of spirit and a muscular liberal conscience that broke the bounds of Jane Austen's world.

"I MUST TELL YOU for your instruction that the Captain says, Miss Austens novels are on every body table, which solely means the Jerseys Londonderrys &c." So Darwin wrote to Caroline from Rio de Janeiro, early in the voyage. Darwin was born into Jane Austen's world; her novels were published during his boyhood, and she died in 1817, not yet forty-two, fourteen years before Darwin sailed. FitzRoy, in contrast, was a sprig of the aristocracy, descended as his surname says from one of Charles II's bastard sons by his mistress Barbara Villiers (Pepys' "my Lady Castlemayne"), and cousin to the marquis of Londonderry, a Tory grandee. The Darwins, like the Austens, were of the gentry of rural England when the total population of England and Wales was still around ten million, and metropolitan London, though it counted more than a million souls, was the only city in England with more than one hundred thousand. The English gentry (but this is still true today) were divided into the few who lived in town and all the rest, who were rural by passion and by principle. Thus, Darwin's sisters and cousins mentioned repeatedly and with bafflement in their letters that brother Erasmus had developed "the most extraordinary taste for London." Not Wordsworth, surely not Shelley nor Byron, but evidently Jane Austen spoke to their lives: nearly all literary references in this correspondence were to characters and quirks of behavior in her novels—*Persuasion; Pride and Prejudice; Emma*—and the references were lighthearted, glancing, taking familiarity for granted. The familiarity was ingrained in their lives. And so, for five years, sisters and cousins chronicled for Darwin the extended family visits and excursions, marriages for love or money, births, sicknesses, deaths, houses and horseflesh, incomes and inheritances, a young friend who had at last secured an army commission, another sent to India to make his way. Ever recurring was the interest in who was about to take holy orders and be preferred to which living—the quiet country vicarage with enough income attached to give a gentleman who happened to be a younger son the security to marry.

A letter to Darwin from his cousin Charlotte Wedgwood is archetypal. She described most amusingly the wedding of her brother Hensleigh:

> He had been very unwell all the week & was in bed Sunday & Monday morning being to be married on Tuesday & he thought himself so bad that he had written a note, to say that the marriage must be put off a couple of days when luckily his doctor arrived, told him he was quite well, recommended him some mutton chops & wine which so restored him that his note was burnt, . . . her gown did not arrive in time & she was obliged to strip one of her bridesmaids & be married in a borrowed one, & still worse she had to wait what seemed a long time in the church . . . bad as this beginning was, for the rest of the time he cut a very good figure & he & the bride both took off their spectacles for the ceremony.

Then Charlotte announced her own engagement to be married, to a Mr. Charles Langton:

> He is a clergyman but has no living & has only a very small income now, but he was tutor to Lord Craven who has many livings in his gift & he has no doubt that he shall have one of them . . . I looked forward to seeing you established in your parsonage but now I suppose I shall receive you first in mine.

Darwin had left England also imagining that he would enter the church. Though he had earlier felt qualms about the depth of his religious commitment and though he wrote to Henslow that his father had initially worried that the voyage would unfit him "to settle down as a clergyman," this was the future that he and his family and friends foresaw. Such a prospect was entirely unexceptionable. In the course of the correspondence before his return, some eighteen friends and relations who were in or entering or planning to enter the church were mentioned. Indeed, this was compatible with the pursuit of science—which then had hardly emerged as a way to make a professional career. Henslow and Sedgwick both were ordained.

THE LETTERS titrate the change in Darwin: the country parson, the natural historian. Early in the voyage, Catherine Darwin wrote surprising news of a young woman named Fanny Owen, who had been a neighbor, childhood playmate, and close friend for many years—and who, to judge from a number of *her* letters

(from before the voyage), was flirtatious, sweet, fond of Darwin, but silly. Darwin's sisters evidently thought he was more than half in love with Fanny; and he had not been gone from England a fortnight when she told Caroline she was engaged to marry another. Darwin, in Brazil by the time Catherine's letter caught up with him, wrote back, "really melting with tenderness... between crying & laughing." Then Fanny Owen, before her marriage, wrote to him several times herself, always with affection; once, perhaps wistfully, she said, "I hope too my dear Charles your expedition is answering all your most sanguine expectations, that you are enjoying yourself in every way as much as possible—and when you do return to the little Parsonage, and want *the little wife,* 'pray give me a commission to look out for her.' " But Darwin employed the same symbol. It was a personal myth. During his first exploration of the Amazonian rain forest, he wrote to his sister Caroline, "I like this sort of life very much: I can laugh at the miseries of even Brazilian travelling.... Although I like this knocking about.—I find I steadily have a distant prospect of a very quiet parsonage, & I can see it even through a grove of Palms."

His sisters took up the theme, and made the first year a counterpoint of loving nagging. Catherine wrote in July of 1832, saying, in part:

> I can conceive no thing more extraordinary and interesting than to be quietly living in a Brazilian Cottage,—but do not let the Cottage put the Parsonage out of your head, a far better thing, and which we were rejoiced to hear continued to be a vista to your prospects. I hope you will in all probability find Fanny Wedgwood [not Fanny Owen] *disengaged* and sobered into an excellent Clergyman's Wife by the time you return, a nice little invaluable Wife she would be.

(But Fanny Wedgwood died less than a month later, aged twenty-six, of what one description makes plain was appendicitis.) Susan wrote, in August, "I am very much pleased to find the quiet Parsonage has still such charms in your eyes. it is so delightful to look forward & fancy you settled there." The letters had been reporting a procession of marriages among family and friends; yet, Susan said, "in spite of this marrying year I am sure you will find some nice little wife left for you." In September, Caroline wrote, "Pray be prudent & careful. I often make a day dream of seeing you so happy in your Parsonage."

By the time Darwin received that letter, he was poised in balance. In mid-November, in a letter to cousin William Darwin Fox, he wrote:

> Poor dear old England. I hope my wanderings will not unfit me for a quiet life, & that in some future day, I may be fortunate enough to be qualified to become, like you a country Clergyman. And then we will work together at Nat. History, & I will tell such prodigious stories, as no Baron Monchausen ever did before.—But the Captain says if I indulge in such visions, as green fields & nice little wives &c &c, I shall certainly make a bolt.—So I must remain contented with sandy plains & great Megatheriums.

Darwin next referred to that personal myth in a letter, also to Fox, the following spring:

> It is, as you say, a serious evil, so much time spent in wandering.—I often conjecture, what will become of me; my wishes certainly would make me a country clergyman.—You expect sadly more than I shall ever do in Nat: Hist:—I am only a sort of Jackall, a lion's provider; but I wish I was sure there were lions enough.

The tone is notably tougher, and the letter goes on with the delights of collecting, of geology, of microscopy.

Never again did his letters mention becoming a clergyman. The women of the family took a while to recognize the transition. At the end of May of 1833, on receiving a packet dating to the previous September, Darwin started a letter to Catherine, saying at one point, "I have worked very hard (at least for me) at Nat History & have collected many animals & observed many geological phenomena: & I think it would be a pity having gone so far, not to go on & do all in my power in this my favourite pursuit; & which I am sure, will remain so for the rest of my life." Yet that autumn, as the voyage evidently stretched its planned duration, Catherine wrote, "I cannot help being rather grieved when you speak so rapturously of the Tropics, as I am afraid it is a still stronger sign, how very long it will be, before we shall have you again, and I have great fears how far you will stand the quiet clerical life you used to say you would return to." Before he could have received that, though, Darwin was writing to Caroline about a planned trip to the interior and, with some anxiety, about the expenses he was regularly running up, which his father had to meet. He went on:

> I should be very glad if my Father would make a real account against me, as he often says jokingly.—I hope he will not think I say this impertinently: The sort of interest I take in this voyage, is so different a feeling to any thing I ever knew before, that, as in this present instance I have made arrangements for starting, all the time knowing I have no business to do it.... I have just packed up a Cargo of specimens. I send home nearly 200 skins of birds & the smaller quadrupeds & a fine set of fossil bones.—There is one skeleton, sufficiently mutilated, of an animal, of which I do not think there exists at present on the globe any relation.

In July of 1834, writing his first letter to another Cambridge friend, Darwin looked back as if across a chasm he had traversed:

> I should much like to hear ... if you are not a married man, & may be nursing, as Miss Austen says, little olive branches, little pledges of mutual affection.—Eheu Eheu, this puts me in mind, of former visions, of glimpses into futurity, where I fancied I saw, retirement, green cottages & white petticoats.—What will become of me hereafter, I know not; I feel, like a ruined man, who does not see or care how to extricate himself.—That this voyage must come to a conclusion, my reason tells me, but otherwise I see no end to it.—It is impossible not bitterly to regret the friends & other sources of pleasure, one leaves behind in England; in place of it, there is much solid enjoyment, some present, but more in anticipation, when the ideas gained during the voyage can be compared to fresh ones. I find in Geology a never failing interest.

And the next day he began a long letter to Henslow—vigorous, assured, and full of marvels. Books that Henslow had sent, just received, were invaluable; his letters were wonderfully encouraging. Darwin's notes were becoming bulky, "about 600 small quarto pages full." He had made an important expedition into the mountains of Patagonia, whose geology was baffling but which he hoped to explain. His collecting had convinced him that previous naturalists, in classifying certain species of corallines, had been arbitrary and artificial. He was consumed by his

Philip Gidley King, Charles Island, Galápagos, *c. 1838*

work and enjoying it hugely—confident, the young lion. "I have just got scent of some fossil bones of a *Mammoth!*, what they may be, I do not know, but if gold or galloping will get them, they shall be mine."

THE PHYSICAL LIFE suited Darwin splendidly (save that he was inevitably sick at sea), and his exuberant vitality in South America draws another contrast to England. The icon we have erected of the Charles Darwin after the *Origin*, a quarter-century and more later, is white bearded, reclusive, ailing, valetudinarian. The Darwin of the *Beagle* was robust, and though that is not in itself a new observation, his letters demonstrate how in the adventure he found physical as well as intellectual manliness. The sisters and cousins, meanwhile, were forever urging him to look after himself—not to get chilled, not to take risks, indeed to leave the expedition early and take another ship home. Thus, Caroline, early in 1883: "I do hope my very dear Charles the cold & rains whilst coasting Patagonia have not made you ill—we are all impatient for your next letter, & if you find all these changes of Climate do not agree with your health come home & think of your snug parsonage." Some of this may be discounted as the English nanny impluse, but the letters were also forever reporting sicknesses of people at home.

So many were incapacitated as to establish chronic illness as an upper–middle class norm. Among those closest to Darwin, his father suffered from gout and other ailments and had largely retired from the practice of medicine, and when he was well enough to make an excursion to York, this was news. Fanny Owen, after she married, wrote only once more; after she had borne her first baby, she wasted away, constantly ill. Catherine wrote to Darwin, two years out, "Poor Fanny is still very unwell; you would hardly know her, she is so changed, so delicate, pale, & thin; but so very charming and affectionate, quite like her dear old self." William Darwin Fox had a weak chest that prevented his taking up the parish he had been offered in the north of England, and in his letters he dwelt upon lassitude and infirmity. One hears the invalid quaver of his voice, and he not yet thirty. Two letters that crossed epitomized the contrast. From Caroline, on September 1, 1833: "Susan wrote last from Osmaston & she will have told you how thin & unwell poor William Fox was looking. he often talked about you and with great interest." On the twentieth of the same month, Darwin wrote a long travelogue to Caroline from Buenos Aires, saying, in part:

> I am become quite a Gaucho, drink my Mattee & smoke my cigar, & then lie down & sleep as comfortably with the Heavens for a Canopy as in a feather bed.—It is such a fine healthy life, on horse back all day, eating nothing but meat, & sleeping in a bracing air, one awakes as fresh as a lark.

Robert Waring Darwin had initially opposed his son's plan to join the *Beagle*. Charles had been the cosseted, younger son, lively and good hearted, yes, but lacking a

clear, serious sense of what he wanted to do. His father had had reason to worry, but his concern gradually gave way to pride in the realization that his son was accomplishing something extraordinary. Toward the end of November of 1835, Susan wrote to Darwin—the *Beagle* soon to be heading toward Australia—that a packet containing an installment of his journal had arrived safely. They had been alarmed about it, as the ship he had told them he would send it by had been wrecked:

> I don't know what Ship it did come in, but your heart wd certainly have been broken if it had been lost. . . . We are now reading it aloud, and Papa enjoys it extremely except when the dangers you run makes him shudder: Indeed I think the escapes you have had of different dangers are quite providential! . . . I cannot think how you cd write such a collected account of your travels when you were Galloping so many miles every day.

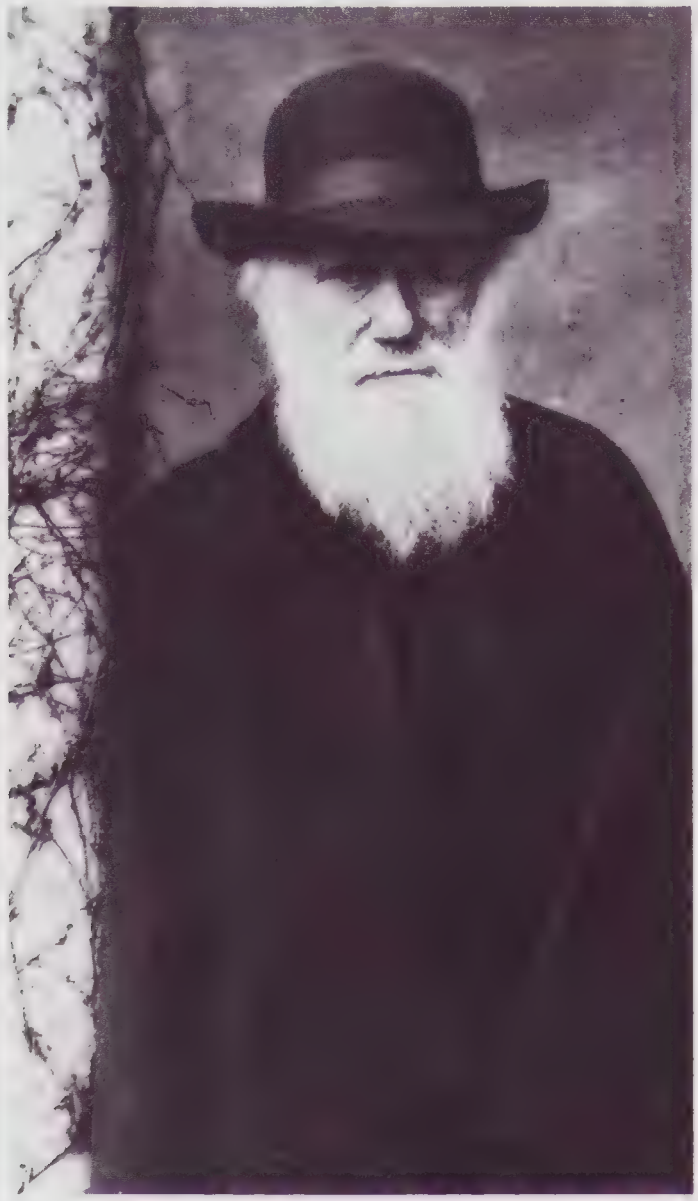
Then Susan relayed a judgment that would have struck them all wonderfully. Adam Sedgwick had recently written to one Samuel Butler, who was headmaster of Shrewsbury School, where Darwin had gone. In a note to Robert Waring Darwin, Butler had sent an extract of Sedgwick's letter, "which was as follows about you," Susan said. She quoted Sedgwick:

> 'He is doing admirably in S. America, & has already sent home a Collection above all praise.—It was the best thing in the world for him that he went out on the Voyage of Discovery—There was some risk of his turning out an idle man: but his character will now be fixed, & if God spare his life, he will have a great name among the Naturalists of Europe.'—I think this paragraph we ought to copy out in every Letter that goes to Sydney lest this shd miscarry. My dear Charley I am so happy you have this reward for all your excessive labour & exertions.

Several weeks later, when John Stevens Henslow sent the family some copies of the pamphlet containing excerpts of Darwin's letters on natural history, Robert Waring Darwin wrote to thank him—five sentences, ending, "I thought the voyage hazardous for his happiness but it seems to prove otherwise and it is highly gratifying to me to think he gains credit by his observation and exertion. There is a natural good humored energy in his letters just like himself."

The day Darwin landed at Falmouth, in the fall of 1836, he took a coach at once for Shrewsbury, where his sisters and father welcomed him with joy. He plunged into the exploitation of his five years' labors, staying for the most part in London, with his brother, Erasmus, but visiting Cambridge, then Shropshire, and this time driving across to the Wedgwoods as well. Letters now are full of the exhilaration of his being back (his father was hale, his sisters unchanged; they found him his old self, if thin), but full, also, of rocks, shells, bones, plants, birds, pickled animals, problems of classification, the need to learn German, the Geological Society, the network of naturalists. Charles Lyell, the eminent geologist, whom Darwin had not known before, was friendly and kind, and Darwin felt this proudly. London, Cambridge, and the professional life in natural history commanded his energies.

Never mentioned by Darwin and referred to only glancingly by his correspondents to the end of 1836 was Emma Wedgwood, another—the youngest—of his Wedgwood first cousins, and a year older than he. With amusing tact, though, the editors summarize, in a couple of sentences each, several letters that *she* wrote that fall to friends and relations. In one, to a sister-in-law, Emma mentioned that she was reading a book of Argentine explorations "to get up a little knowledge for him" when Charles came to visit. In another, she seemed convinced that, of course, Darwin's journals were worth publishing. Three years later, Charles Darwin married Emma Wedgwood. They lived in London for a while, but in 1842 settled at Down House, in Kent, sixteen miles southeast of London. So after all, one may think, Darwin found his nice little wife and the secular equivalent of a country parsonage. Yet from there, transformed even while returning to his roots, he extended that transformation to the intellectual life of his century and of ours. ●



Unknown photographer, Portrait of Charles Darwin, *1880*

HORACE FREELAND JUDSON, Henry R. Luce Professor in The Writing Seminars at Johns Hopkins University, is the author of THE EIGHTH DAY OF CREATION, *a history of the chief discoveries of molecular biology, and* THE SEARCH FOR SOLUTIONS, *an introduction to the art of scientific discovery.*

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Laurence A. Marschall

Pablo Picasso, La Muse, *1935*

More Than Meets the Eye

THE MIRROR AND MAN, *by Benjamin Goldberg; University Press of Virginia; 260 pages; $20.00*

Archaeological digs at El-Badari, some two hundred and fifty miles south of Cairo, have unearthed fragments of stone mirrors more than six thousand years old. From these, the earliest known examples, to the orbiting solar reflector of NASA's space telescope, history shimmers with evidence of man's fascination with mirrors—his tireless pursuit of reflections in crystals, mica, steel, polished bronze and silver, and even in bowls of blood.

It has not all been for vanity's sake, however; early mirrors were prized for their ability to reveal the supernatural. In medieval Europe, heretic scryers claimed they could call forth spirits and could see the future in thumbnails polished with holy oil. Fifteenth-century German pilgrims held mirrors up to relics to capture reflections of divinity for their relatives back home. And people throughout history have equated man's mirror image with his soul: in the nineteenth-century German novel *Story of the Lost Reflection,* for instance, the protagonist sells his reflection to the devil in return for worldly rewards. Muhammadans and Jews turn mirrors to the wall during mourning, lest the spirit of the deceased steal their souls from the glass. Similarly, to break a mirror, superstition holds, is to lose one's soul, and hence incur seven years' bad luck.

In his last chapter, "The Subjective Mirror," Benjamin Goldberg, a retired director of the U.S. Army's night vision laboratory, in Fort Belvoir, Virginia, draws parallels between such age-old imagery and the finding in contemporary psychology that the reflection a man sees in a looking glass depends upon his view of himself and of the world—that he sees his imagined self, not his real self. If this is true—if the image is a synthesis of, in Goldberg's words, "his identity, his uncertainties, and his desires"—perhaps the mirror does, in some sense, reveal man's soul.

THE SOCIAL BRAIN: Discovering the Networks of the Mind, *by Michael S. Gazzaniga; Basic Books; 219 pages; $17.95*

The corpus callosum is a broad bundle of nerve fibers that connects the left and right hemispheres of the brain. When this connection, and a related structure, are cut, usually as a treatment for severe epilepsy, the patient's left hand literally ceases to know what the right hand is doing. Studies of such "split brain" patients, which have been going on for several decades, have given rise to the popular notion that the brain contains two minds—one, in the left hemisphere, that governs rational thought and language, and one, in the right, that is the seat of emotion and creativity.

In truth, we are of many more than two minds, concludes neuroscientist Michael Gazzaniga, reviewing the results of his twenty-five years of research. Human behavior, he maintains, is governed by a confederation of brain systems, or "modules." Like the mental "faculties" that

were proposed by nineteenth-century phrenologists, these modules operate independently but in communication with one another. Unlike faculties, however, which were thought to occupy distinct areas in the brain and to govern aspects of character, each module seems to be physically dispersed, and they perform such functions as the generation of visual images from memory, the correlation of sensory stimuli, and the initiation of muscular activity.

Gazzaniga believes that personality results from the collective interaction of modules; "the human mind," he writes, "is more of a sociological entity than a psychological entity." Still, one module—the one capable of language—creates a conscious sense of self, by constantly interpreting and rationalizing the behavior of the others. If the mute right brain of a split-brain patient is given an order to rise, the patient will do so, and, when asked why, will offer a logical explanation, such as "Going into my house to get a Coke." The language-generating portion of the left brain, lacking access to the real motive for rising, constructs a story to justify the impulse.

Whether or not the behavior of split-brain patients can be used to explain the workings of an intact brain is, as Gazzaniga readily admits, open to question. And to leap from there to conclusions about the formation of religious beliefs and the failure of social welfare systems, as he does in his final two chapters, may stretch induction beyond the limits. "Every brain scientist in the history of the world who talks about the meaning of neuroscience for larger questions has come off as foolish," Gazzaniga warns, then proceeds, with wit, style, and only occasional lapses in credibility, to ignore his own warning.

SEVEN CLUES TO THE ORIGIN OF LIFE: A Scientific Detective Story, *by A. G. Cairns-Smith; Cambridge University Press; 131 pages; $17.95*

The Athenian dramatist Aristophanes considered humans to be "ephemeral, wretched, mortal and dreamlike"—nothing more than "weak creatures of clay." Today, biochemist A. G. Cairns-Smith proposes to make the metaphor literal; all life, he argues, began as clay, evolving from sedimentary minerals in the abundant swamps and muddy deltas of the ancient earth.

In this brief popular version of his more comprehensive *Genetic Takeover,* Cairns-Smith expounds the unorthodox view that the first organisms were built not of complex proteins and DNA but of certain clay crystals. These silicon-based crystals had the ability to replicate, and their offspring often possessed slight modifications in structure, much like mutations. Thus, over many generations, the crystals might have begun to incorporate organic, carbon-based compounds. Eventually, Cairns-Smith proposes, the carbon compounds gained prominence, and the clay crystals became superfluous. The result: a "genetic takeover" of the early, low-tech silicon life-forms in favor of what the author calls the high-tech biochemistry of life today.

Cairns-Smith unfolds the clues leading to his conclusion in the style of a fine detective novel; his title, in fact, is taken from an Arthur Conan Doyle story, "The Naval Treaty," in which Sherlock Holmes coolly assures a skeptical client that he has already spotted seven clues to a seemingly insoluble mystery. Cairns-Smith's case, like Holmes's, is laid out smoothly, and yet, as for all theories about the beginnings of life, the evidence is purely circumstantial.

TO ENGINEER IS HUMAN: The Role of Failure in Successful Design, *by Henry Petroski; St. Martin's Press; 247 pages; $16.95*

Mistakes will be made, but in most professions they can be buried beneath piles of paper or mounds of sod. Not so in engineering, wherein a critical design error, sometimes merely a misplaced decimal point, can precipitate disaster. The fire on the *Hindenburg,* the collapse of the Tacoma Narrows Bridge, the leak of toxic gas from a Union Carbide plant in Bhopal, and the explosion of the shuttle *Challenger* all were triggered by flaws in engineering.

Duke University engineer Henry Petroski presents case studies of such catastrophes not to point the finger of blame but to illuminate the nature of the engineering enterprise itself. A goal of all engineering—from the design of buildings to the creation of electronic toys—is to avoid failure. Yet major advances in materials, fabrication, and safety are frequently fashioned from the rubble of past mistakes. Engineering essays, like written ones, require constant revision; a mechanical failure is just nature's way of asking for another draft.

Flawless first drafts do appear, however—sometimes from surprising sources. The pavilion that housed London's Great Exhibition, in 1851—the first world's fair—was designed by a gardener, who modeled the building's elaborate pattern of girders after the ribs of a lily pad. The design had been tested only once, on a small greenhouse, and critics considered the scaleup to a seven-hundred-and-fifty-thousand-square-foot pavilion an invitation to disaster. "Mathematicians have calculated that [the building] will blow down in the first strong gale," wrote Prince Albert to the king of Prussia when asked if it was safe to visit during the Great Exhibition. Despite such dire predictions, Petroski notes, the Crystal Palace stood fast, providing a rare exception to his contention that engineering progresses more by trip-ups than by triumphs.

SYMPATHY AND SCIENCE: Women Physicians in American Medicine, *by Regina Markell Morantz-Sanchez; Oxford University Press; 464 pages; $24.95*

Little more than a hundred years have passed since the Harvard professor Edward H. Clarke warned that higher education for women would produce "monstrous brains and puny bodies; abnormally active cerebration and abnormally weak digestion; flowing thought and constipated bowels." And in that brief time, this warning notwithstanding, women have come to constitute roughly half the nation's professionals.

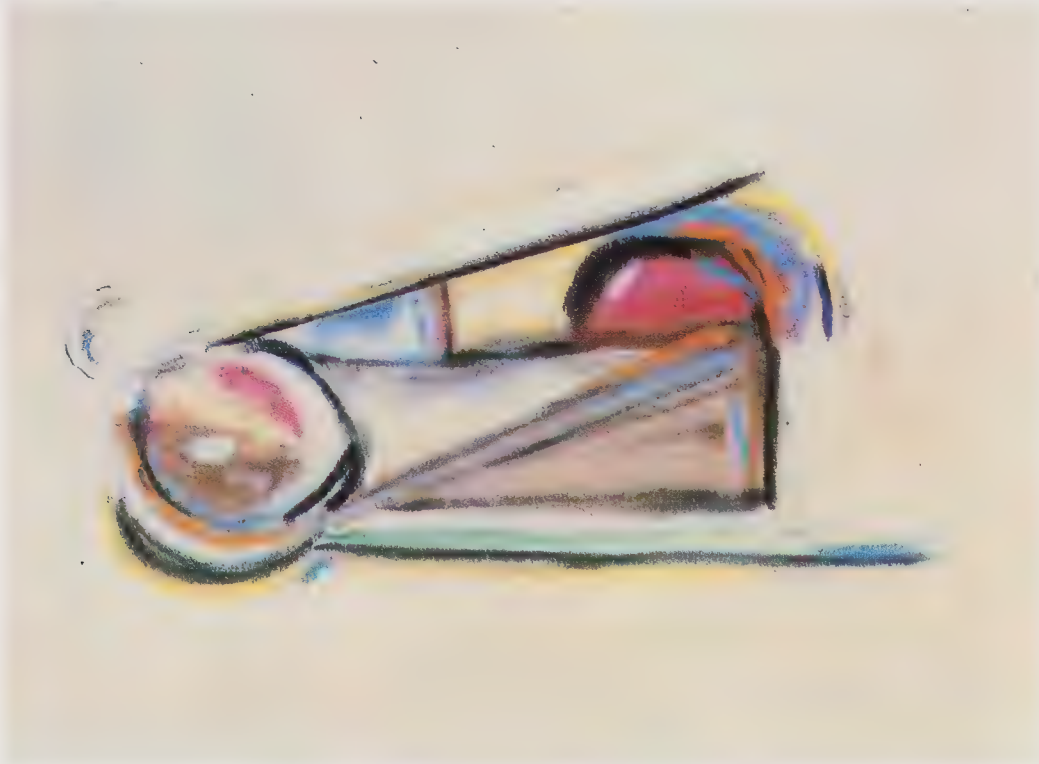
Not so in medicine. Women's participation in the healing arts peaked in 1910, then declined for nearly fifty years. At the turn of the century, women's medical colleges flourished in Philadelphia, Boston, New York, and Baltimore. Female doctors of the era argued that women, because of their sympathetic nature, made unique contributions to medicine—a view seemingly borne out by their pioneering role in shaping public health legislation and founding child welfare agencies.

But as the medical community strove to raise its professional status—by establishing exclusive academies and emphasizing scientific objectivity and total commitment to work—it increasingly ostracized female physicians. Students from women's medical colleges were barred from teaching hospitals, and traditional female specialties, such as obstetrics, fell in prestige. Women who wanted to raise families as well as practice medicine were criticized as being uncommitted.

Only recently, says historian Regina Morantz-Sanchez, has the medical community begun to question such biases and revive the turn-of-the-century notion that the profession might benefit from "feminine" qualities. In 1984, when Lee Roy Hendricks, then chairman of obstetrics at Stanford University, berated chief resident Zena Levine for getting pregnant—accusing her of doing a disservice to her colleagues and threatening to appoint no more women—he was forced, under pressure from other faculty members, to resign. "Less than fifteen years ago," remarks Morantz-Sanchez, "it would have been Dr. Levine who would have resigned." ●

LAURENCE A. MARSCHALL is a professor of physics and director of the observatory and planetarium at Gettysburg College, in Pennsylvania.

Dominic Olivastro



Morton Livingston Schamberg, Composition, *1916*

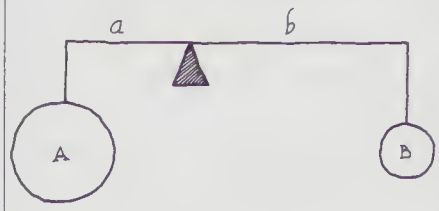
A Sufficiently Long Lever

Perhaps the citizens of Syracuse, in the third century B.C., thought Archimedes too prone to enthusiasm. History records that he was so exhilarated upon discovering the principle of the lever that he boasted, "Give me a place to stand on, and I can move the earth." King Hiero, according to the biographer Plutarch, was "struck with amazement" at this. Yet Archimedes was entirely correct. Given a sufficiently long rod and a sufficiently sturdy fulcrum (and ground, of course, on which to rest that fulcrum), there is no theoretical limit to the amount of weight a person can lift with a lever.

The lever is one of the six elementary machines—devices that cannot be deconstructed into simpler parts. The others are the wedge, the screw, the wheel, the inclined plane, and the pulley, whose action, in fact, can be derived from the principle of the lever. Archimedes proved that a pulley is nothing more than an infinite series of levers, pivoted at the center.

When Hiero asked him to prove his boast, Archimedes constructed a system of pulleys and attached it to a ship in dry dock, heavily laden with passengers and supplies. Then, wrote Plutarch, "with no great endeavour, but only holding the head of the pulley in his hand and drawing the cords by degrees, he drew the ship in a straight line, as smoothly and evenly as if she had been in the sea."

Archimedes' mathematical proof of the lever principle, in *On The Equilibrium of Plane Figures,* is simple. Consider the figure below. If two unequal weights, *A* and



B, are balanced over a fulcrum that is distance *a* from *A* and distance *b* from *B,* then $A \times a = B \times b$, or $A/B = b/a$. In other words, the ratio of the weights is inversely proportional to their respective distances from the fulcrum. If length *b* is five times length *a,* then *B* will exert a force on *A* that is five times greater than *B*'s own weight. The lever amplifies the force applied at its longer end, in proportion to the ratio of the longer end to the shorter. This ratio, by the way, also applies to the vertical distances that *A* and *B* travel: *B* must sink five feet to make *A* rise one foot. (Given a pole long enough, Archimedes might have been able to move the earth, but he would have had to lower the lever quintillions of miles to budge the world a single inch.) Physicists speak of *A* as the load—the object to be moved—and of *B* as the effort required to move the load; the place on the lever where force is applied is called the point of effort.

The lever, of course, was used long before Archimedes supplied his mathematical explanation of its function. We cannot date it, because the first levers undoubtedly were tree limbs and sticks that left no clues as to their use. But wherever man has made pictures of his labors, there have been renditions of the lever. One Assyrian relief from the ninth century B.C. shows a large idol, suspended by ropes, being lifted with a beam balanced on a makeshift post. Little attention was paid to realistic perspective in such carv-

ings—the sizes of people and deities were usually related to their status, not their appearance in the picture plane—yet none show a lever with unrealistically small ratios. The principle may not have been mathematically proved, but it was understood.

Besides carvings and bas-reliefs, we have the mute evidence of such spectacular construction projects as Stonehenge and the Pyramids, which must have required contraptions based on the lever for the lifting of their massive stones. Some of the stone blocks that make up the Pyramids have longitudinal flanges and slits—perfect places in which to secure a rope whose other end would be attached to a crane, which, in its simplest form, was probably a horizontal pole, acting as a lever, balanced on a vertical post, acting as a fulcrum.

We can get an idea of how such a crane would have worked from a common lever still used in Egypt and India. In Egypt, it is called a shadoof, and it consists of two long poles, one shaped like a Y and driven into the ground, usually near a riverbank, and the other balanced between the prongs of the Y. On one end of the horizontal pole hangs a large bucket. The bucket is lowered into the river, then the load is raised with a rope hanging from the opposite end. In India, these devices are quite large, and men will walk along the horizontal beam—toward the river to lower the bucket, then back toward the bank to raise it.

Few modern lever-driven machines are as uncomplicated as the shadoof. Several short levers, in a complex interlocking pattern, can do the same work as a single long one and are far less awkward. Imagine, for example, lifting a truck that weighs 12,800 pounds. It could be done with a 65-foot-long pole and a sturdy fulcrum: I would place the pole between me and the truck so that 64 feet of it was on my side of the fulcrum and only 1 on the truck's. The amount of force I would then need to exert would be 1/64 of the truck's weight, or 200 pounds. But I could also use a 5-foot pole, placed over the fulcrum at a ratio of four to one. I would then need to exert 3,200 pounds of force—admittedly an impossible task. A second 5-foot lever, positioned over a second fulcrum at a four-to-one ratio, with its short end placed above the long end of the first lever, would reduce the force needed to 1/4 of 3,200 pounds, or 800 pounds. Finally, a third 5-foot lever under the second would reduce the required force by 1/4 again, to 200 pounds. I would still have to lower the third lever 64 feet to raise the truck 1 foot, but instead of using one pole 65 feet long, I could accomplish the task with three levers totaling only 15 feet. It was this principle that Archimedes applied when he constructed a combination of pulleys sufficiently compact to hold in his hands, yet efficient enough to pull a ship across the ground.

Complexity is not the only difference between lever-driven machines and the primeval crane. Many modern devices, at first glance, might not be taken for levers at all, because the positions of their fulcrums, loads, and points of effort differ from the shadoof's intuitively obvious arrangement. Consider the wheelbarrow, in which the fulcrum lies at one end, effort is exerted at the other, and the load lies in between. Load and fulcrum have traded places, but Archimedes' equation still holds: the distance between point of effort and fulcrum, being greater than that between load and fulcrum, amplifies the exerted force. Such a lever is useful when the directions of effort and lift must be the same rather than opposed, as in the shadoof.

In one respect, though, the wheelbarrow-type lever is identical to the shadoof. Both require that a worker pay a price in distance for his mechanical advantage: if the effort is amplified five times, the point of effort will have to move vertically five times farther than the load. There is a third type of lever, however, which, rather than offering power in exchange for distance, offers distance in exchange for power. Fulcrum and load are at opposite ends of such a lever, and because the point of effort lies between them, the distance from that point to the fulcrum is always *shorter* than the distance from fulcrum to load. It takes *more* force to move the load with this lever than without it. On the other hand, every movement at the point of effort results in a larger movement of the load. Such a lever is a motion multiplier; it amplifies slight movements into larger ones.

Consider, for example, the gas pedal of a car, whose point of effort (where the driver's foot meets the pedal) lies between the fulcrum (the fire wall) and the load (the rod that controls fuel flow into the engine). Pressing that rod directly with his foot would require less effort of the driver than using the pedal; but because broad gestures are harder to control precisely than are slight ones, the driver who lowers his foot several inches to increase the flow of fuel will have less control over the car than will the driver who moves his foot a mere eighth of an inch to gain the same effect. Hence, the pedal's usefulness in multiplying slight movements into actions big enough to effect the flow of fuel. This type of lever can also be used for the opposite purpose—turning big motions into small ones. When a truck scale, for instance, sinks beneath the weight of a loaded rig, a collection of interconnected levers translates that big downward plunge into the slight movement of a needle over the finely calibrated face of a gauge.

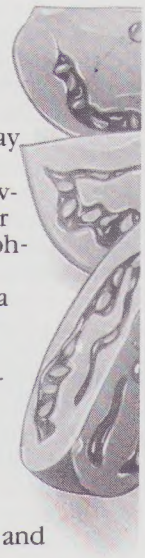
All three types of levers are found in nature as well as in machinery. It was a truism of nineteenth-century anatomy that all were present in the human body, and many anatomists today agree. The head is seen as a lever of the first type, with the atlas vertebra for its fulcrum; the back of the skull as the point of effort; and the face and forehead as the load. The second, wheelbarrow-type lever is represented by the foot, rising on tiptoe: the ground is the fulcrum; the calf is the point of effort; and the body's weight on the ankle is the load. Of the third type of lever, a favorite example is the arm, lifting a weight in the hand: the elbow is the fulcrum; the point on the forearm where biceps meet bone is the point of effort; and the object in the hand is the load.

The lever's motion-multiplying effect makes it possible to raise the entire lower arm by making a small muscular contraction, suggesting that the conditions under which humans evolved must have placed a higher premium on moving efficiently than on carrying the heaviest possible loads. Indeed, the arms and legs of most animals are levers of the third class, and it can be seen in them how evolution and mechanics interact. Any vertebrate's leg, for example, is a lever in which the load point is the end of the foot, the fulcrum is the knee (or its equivalent), and the point of effort lies below the joint where muscle meets bone. In a fast-moving animal, such as the horse, the muscle attaches quite close to the joint, so the distance between fulcrum and load is far greater than the distance between fulcrum and point of effort. Thus, the horse must make a comparatively large effort to move its leg, but the motion-multiplying effect is so great that each contraction produces a huge stride—just what is required for a species that eludes predators by swiftness. On the other hand, the groundhog's leg is so arranged that muscle meets bone rather far from the joint. Less of the animal's work is expended in fighting mechanical disadvantage, so more of it is delivered to the load. It gets less distance out of each contraction but more strength—as befits an animal that must burrow constantly.

Ever since Archimedes, the principle of the lever has been used to create a remarkable variety of surprising machines. Here are three, all motion multipliers and each a test of the reader's mechanical imagination.

(1) The device below has two short arms of equal length, *AD* and *BC*, and two long arms, *AB* and *DC*, also of equal length. The four arms form a parallelogram, connected at three corners by free-moving pivots. The fourth pivot, at point

A defense against cancer can be cooked up in your kitchen.



There is evidence that diet and cancer are related. Some foods may promote cancer, while others may protect you from it.

Foods related to lowering the risk of cancer of the larynx and esophagus all have high amounts of carotene, a form of Vitamin A which is in cantaloupes, peaches, broccoli, spinach, all dark green leafy vegetables, sweet potatoes, carrots, pumpkin, winter squash, and tomatoes, citrus fruits and brussels sprouts.

Foods that may help reduce the risk of gastrointestinal and respiratory tract cancer are cabbage, broccoli, brussels sprouts, kohlrabi, cauliflower.

Fruits, vegetables and whole-grain cereals such as oatmeal, bran and wheat may help lower the risk of colorectal cancer.

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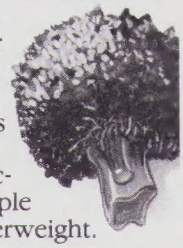
Be moderate in consumption of alcohol also.

A good rule of thumb is cut down on fat and don't be fat. Weight reduction may lower cancer risk. Our 12-year study of nearly a million Americans uncovered high cancer risks particularly among people 40% or more overweight.



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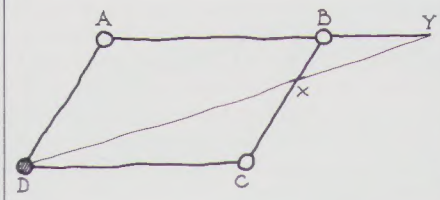
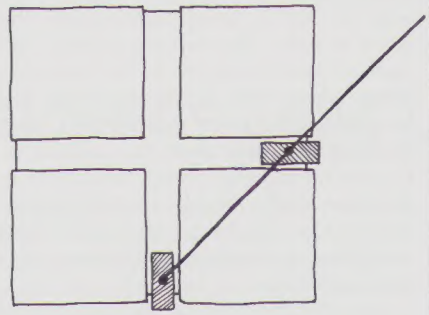
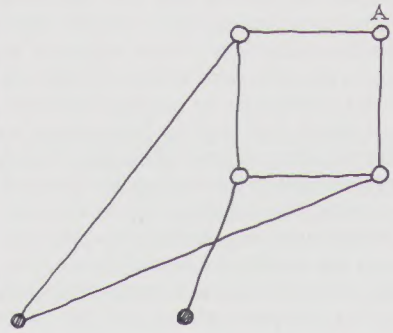
D, is fixed; the two arms that meet there can rotate full circle, but the pivot must remain stationary. A line extends beyond the parallelogram to point *Y*. And there is a point *X*, located on the arm *BC*, such that the line *DXY* would be straight. If we fix a pen at point *Y* and trace a design, that motion will be translated to all other parts of the machine. Imagine that a pen also has been fixed at *X*. As *Y* moves, what trail will *X* trace?



(2) In this device, an arm is attached by pivots to two wedges—blocks placed on tracks, along which they are free to travel. If the arm is rotated clockwise, the wedge on the vertical track will move up and the horizontal wedge will move to the right. If we continue rotating the arm, the wedges will reverse directions, always avoiding collision in the center of the square. If a pen is placed at the end of the arm, what figure will be traced as the arm is rotated?



(3) This device is composed of seven arms. The longest two are of equal length and meet at a fixed pivot. The other ends of these two segments are attached to opposite corners of a rhombus, composed of four arms of equal length and attached to one another with free-moving pivots. The seventh arm extends from one corner of the rhombus to a fixed pivot, and the distance between the two fixed pivots is equal to the length of this arm. The motion of this device is strictly determined: if it moves at all, it can follow only one path. If we place a pen at point *A*, what trail will it trace?



SOLUTIONS

(1) The trail traced by *X* will always be a reduced copy of the one traced by *Y*. The proportion of the two figures will be *DY*/*DX*. The farther *Y* is from *B*, the smaller will be the figure *X* traces.

Proving this is easiest if one works backward. The tracings by *X* and *Y* will have the same shape if lines *DY* and *DX* remain in constant proportion, as they would if the lines connecting *DAY* and *DCX* form triangles of identical proportions. To determine whether they do, move the figure (either in your mind's eye or on the desk where it lies constructed out of cardboard and pins) so that *DAY* forms a right triangle. Now, *DCX* must also be a right triangle whose hypotenuse is part of the larger triangle's.

This machine is a simplified version of the pantograph, an instrument of great importance to engineers until the advent of computers. As described here, it can reproduce any drawing in reduced form. Only minor modifications are needed to construct a pantograph that will enlarge a drawing.

(2) The arm of this machine will trace an ellipse. To see this, draw the device with its arm at twelve, three, six, and nine o'clock. The only curve that will connect all four points is elliptical. The two tracks of the block lie parallel to the major and minor axes of the ellipse, and the distance between pivots is the distance between the foci of the curve. If the two wedges could be made to intersect in the middle of the block, and the two pivots became one, the pen would trace a simple circle.

(3) Point *A* will trace a straight line. The formal proof involves enormously complicated geometry, but the reader who constructs this device from cardboard and thumbtacks will prove it for himself. It is an extraordinary effect.

The device is called a Peaucellier linkage, after Captain Charles-Nicolas Peaucellier, of the French corps of engineers, who invented it in 1873. Oddly, this contraption is, mathematically speaking, the simplest way to draw a straight line. A device with fewer arms or pivots would not do the trick, and, of course, a simple straightedge requires the prior concept of straightness. ●

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Medical Research–building a healthier future

If you've ever been treated for high blood pressure... heart disease...diabetes...or almost any health problem, medical progress based on research has already touched your life.

Because of medical research, polio no longer strikes in epidemic proportions every summer. Today about three-quarters of patients diagnosed as having Hodgkin's disease will survive five years or longer—as opposed to less than half twenty years ago. Current treatment options for people with heart disease and high blood pressure include medication that helps the body's natural regulators to control blood pressure and volume, enabling the heart to function with less strain.

Scientists are now working on new ways of treating such devastating afflictions as heart disease, cancer and Alzheimer's disease. They are testing new enzyme inhibitors that may control or reverse the late complications of diabetes. Forthcoming breakthroughs in understanding biological processes and treating disease may change the quality and perhaps the length of your life.

Medical research leading to such results takes years of patient, often frustrating experimentation by many different teams throughout the public and private sectors of our scientific community. The tasks involved are not simple.

Advances in research stem from a partnership that includes federal agencies such as the National Institutes of Health (NIH) and the Alcohol, Drug Abuse and Mental Health Administration (ADAMHA), universities and teaching hospitals across America, and private industry laboratories. Each partner often works independently to acquire knowledge and test new concepts. They must build on the knowledge developed in all laboratories, and they often coordinate efforts in their search for answers.

Whether an idea originates in a university laboratory or starts with basic product research carried on in the private sector, important findings percolate through the entire scientific community, where each new finding serves as a building block to establish a deeper understanding of what we are and how we function.

Medical research is an expensive process. It needs steady funding for equipment and personnel—even when progress is slow. Government and industry often work with university-based scientists and the medical profession not only in the acquisition of new knowledge and the development of new treatments, but also in funding these advances.

Now more than ever, we all must do our part to help keep the flow of discoveries active and ongoing. If funding for medical research is reduced, major advances in knowledge about some of the most dreaded diseases facing us today could be delayed for years to come.

What can you do?

- *Speak up.* Let your legislators know that you want funding of biomedical research by NIH and other government agencies to be kept at the highest possible levels.
- *Contribute* to voluntary health organizations supporting disease research.

Research-based pharmaceutical companies such as Pfizer are also increasing their financial investment in research. For instance, in 1984 alone, pharmaceutical companies in the United States spent over 4 *billion* dollars on research and product development.

At the same time, we at Pfizer realize the importance of committing more than money to research. As a partner in healthcare, we are continually working to discover new ideas, test new concepts, and turn new understanding to practical and beneficial uses. Now we are working harder than ever to make sure that this nation's medical research effort receives the attention—and funding—it deserves.

For more information on the future of medical research in America, write to Health Research U.S.A., P.O. Box 3852 FR, Grand Central Station, New York, NY 10163.

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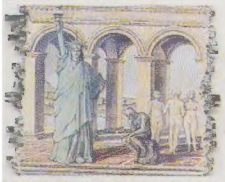
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